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# CROSS-EDUCATION OF THE REPEATED BOUT EFFECT AFTER UNILATERAL ECCENTRIC EXERCISE WITH AND WITHOUT MIRROR VISUAL FEEDBACK

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# CROSS-EDUCATION OF THE REPEATED BOUT EFFECT AFTER UNILATERAL ECCENTRIC EXERCISE WITH AND WITHOUT MIRROR VISUAL FEEDBACK

A THESIS APPROVED FOR THE

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## ABSTRACT

Previous research has demonstrated evidence of the cross education of the repeated bout effect (CL-RBE) to the untrained contralateral limb, however, it has been shown to be weaker in magnitude when compared to the ipsilateral limb. Mirror visual feedback or mirror therapy has been shown to potentially enhance the effectiveness of cross education, but this intervention has not been investigated when looking at the cross education of the repeated bout effect.

**PURPOSE:** The purpose of this study was to investigate if mirror visual feedback could enhance the CL-RBE in the untrained contralateral limb after a single bout of unilateral eccentric exercise. **METHODS:** 28 participants (14 men & 14 women ages 18-35) were placed into 1 of 3 groups (control, no mirror, and mirror) and completed 10 visits which consisted of 2 familiarization visits, 2 eccentric exercise testing visits (1 or 2 weeks apart), and 6 follow-up visits. This study utilized a pre-test/post-test controlled design where participants would perform pre-exercise measurements of maximal isometric strength (MVC), range of motion (ROM), and muscle soreness rating (DOMS). For the 1st maximal eccentric exercise visit, 3 sets of 8 repetitions of maximal effort eccentric bicep curls with their dominant arm using the KinCom isokinetic dynamometer. During this 1$^{st}$ bout, the Mirror group had a mirror placed on the axilla of their non-dominant arm to create the mirror image illusion effect of bilateral exercise of the elbow flexors. The Control group used their dominant arm again for the 2$^{nd}$ eccentric exercise visit while the two experimental groups (No Mirror and Mirror) performed the bout with their non-dominant arm. After each eccentric exercise bout, they would perform the post-exercise MVC, ROM, and DOMS measurements. During these visits, surface EMG data of the biceps and triceps were recorded. These 2 eccentric exercise testing visits had 3 follow up visits (24h, 48h,

and 72h) collecting data for MVC, ROM, and DOMS. **RESULTS:** The Control group and No Mirror group exhibited a repeated bout effect with a significant difference between bouts when looking at MVC and DOMS ($p < 0.05$) with the control group exhibiting the largest magnitude of protection. The No Mirror group did not show any significant differences between bouts when looking at these measures ($p > 0.05$). All groups did not show a significant difference when looking at ROM. All groups did not show a significant difference when looking at EMG RMS between bouts, demonstrating similar muscle activation in all groups between bouts ($p > 0.05$). **CONCLUSIONS:** In conclusion, this study demonstrates the supported findings of the RBE in the control and the CL-RBE in the no mirror group, however, there was no evidence of the cross education of the RBE in the Mirror group when looking at any of the dependent variables. Therefore, mirror visual feedback had no influence on the CL-RBE. Future studies should continue to investigate the use of a mirror to augment the CL-RBE with larger sample sizes and up to 5 follow-up visits. Investigation into mirror placement and the validity of the effectiveness of different positions for the mirror when used during various exercises should be considered as well.

# CHAPTER 1: INTRODUCTION

Muscle damage may occur when the muscle receives a harmful physical, chemical, or biological stimulus. The most common occurrence in daily life is a physical stimulus through sport, exercise training, and/or daily physical activities. The performance of unaccustomed muscle contractions consisting of eccentric contractions (i.e. those where the muscle is lengthening) is often the primary physical stimulus (McHugh et al. 1999). This unaccustomed exercise results in a defined set of symptomatic, functional, and histologic changes that are referred to collectively as muscle damage (Hyldahl et al., 2017). Eccentric exercise leads to muscle damage (EIMD) by causing a disruption of the z-disc structure, intermediate filaments, and contractile proteins to a greater extent than with other types of muscle contractions. EIMD also leads to an increase muscle specific proteins such as creatine kinase (CK) and myoglobin appearing in the blood. Disruption of the sarcomere leads to a loss function that manifests as a decreased ability to generate force and a loss of range-of-motion (ROM). Symptomatically, muscle damage leads to the development of muscle pain/soreness that is often delayed in its onset and thus has been termed as delayed onset muscle soreness (DOMS) (Tiidus, 2008).

Although EIMD and its accompanying prolonged muscle soreness may be undesirable, an adaptation occurs following the recovery process that plays a “protective” role and limits EIMD from the performance of similar bouts of eccentric exercise in the future. Evidence suggests both “neural” (changes in motor-unit recruitment, etc.) and “physical” (changes in expression of structural proteins within a sarcomere, etc.) adaptations occur that attenuate muscle damage from future eccentric exercise. This occurrence of a protective effect after a bout of eccentric exercise has been termed the repeated bout effect (RBE) (McHugh et al., 1999; Mchugh, 2003). The RBE has been shown to last for 6-9 months but begins to diminish after

roughly 8 weeks (Nosaka et al., 2005; Tiidus, 2008; Chen 2016). The adaptations that occur with the RBE have been widely studied but remain somewhat unclear. As mentioned previously, adaptations are generally categorized as neural (e.g. changes in motor-unit recruitment strategies) or physical/peripheral (e.g. changes in the cellular and mechanical properties of skeletal muscle) in nature. There is clear evidence that physical changes occur in skeletal muscle following EIMD, however evidence that nervous system adaptations whereby motor-unit recruitment, firing rates, and/or synchronization of motor-unit firings occur is also growing. A unique motor pattern is used when performing eccentric contractions. This has been shown to result in reduced motor-unit activation (as observed from surface EMG) at a given absolute force when compared to concentric and isometric contractions (Hight et al. 2016). This leads to greater stress being placed on a smaller number of muscle fibers during eccentric contractions which likely contributes to why EIMD occurs more often following eccentric exercise. Increased motor-unit activation as well as decreased antagonist activation (Hight et al. 2016) has been shown with the RBE indicating a change in neural strategy to reduce the stress placed on individual muscle fibers.

An emerging area of research on the RBE involves the transfer of neural adaptations from limb to the other—termed "cross-education." Studies have observed the phenomenon in response to exercise of a single limb leads to enhanced performance of the uninvolved contralateral muscle group (Zhou, 2000; Hyldahl, 2017; Manca, 2017). This phenomenon was first observed in 1984 by researcher Edward Scripture. He observed the transfer of both strength and motor skill to the contralateral limb after unilateral exercise (Scripture, 1984). It is well accepted that neural mechanisms are responsible for cross-education, and the utility of these adaptations has been recognized in a variety of training programs, especially in clinical and rehabilitation

settings (Carr, 2019). In relations to the RBE, studies have shown that performing maximal eccentric exercise in one limb confers the protective properties of the repeated-bout effect to the opposite limb and has been termed the "contralateral repeated bout effect" (CL-RBE) (Hortobagyi et al., Hyldahl, 2017; Chen et al., 2016). While the CL-RBE has been consistently observed little is known about the exact changes in neural strategies that potentially underlie the CL-RBE.

Recent research suggests that the effect of cross-education may be magnified with the use of mirror visual feedback (MVF). Mirror visual feedback involves the individual performing unilateral exercise with a mirror placed along the midsagittal plane, which shows a mirror image of the exercising limb that creates the illusion that the contralateral limb is performing exercise concurrently with working limb (Carr, 2019). This process has been shown to produce specific patterns of brain activity and is hypothesized to activate mirror neurons (Howatson et al., 2013) which are thought to be involved with sensory integration, motor planning, and movement execution (Rizzolatti & Craighero, 2004). Activation of the mirror neuron system have been shown to enhance the cross-education of muscular strength in healthy individuals as well as clinical populations with asymmetric limb disorders (Ramachandran & Altschuler, 2009; Carvalho et al., 2013; Urbin et al., 2015). For example, a study involving individuals using MVF, showed ~27% greater increase in strength in the contralateral limb following 3 weeks of unilateral strength training using a mirror compared to training without MVF (Zult et al., 2016). Given the ability of MVF to enhance the cross-education of neural adaptations following resistance training, it represents an intriguing method to potentially enhance the CL-RBE since it also is dependent upon the cross-transfer of neural adaptation.

Using this mirror visual feedback tool may be helpful in increasing the magnitude of CL-RBE as current research shows that the RBE effect in the contralateral limb is not as strong when compared to the ipsilateral limb (Howatson & Someren, 2007; Chen et al., 2016; Hyldahl et al., 2017). Results in a recent study show that the index of protection (%) gained in the contralateral limb in comparison of the ipsilateral limb (which stays at 100%) peaks at 60 to 80% after 1 day and 1 week, drops to 50% after 4 weeks, and diminishes to baseline thereafter (Chen et al., 2016). Currently to the author's knowledge there is no research investigating the augmentation of cross education of the RBE with the use of mirror visual feedback.

### 1.01. Purpose

Therefore, the purpose of this study was to investigate whether the use of MVF enhances the cross-education of the RBE in the contralateral limb following a single bout of unilateral eccentric exercise.

### 1.02. Research Questions

1. Does MVF during a single bout of unilateral eccentric exercise enhance the CL-RBE compared to unilateral eccentric exercise without MVF?
2. Does MVF during a single bout of unilateral eccentric exercise alter motor unit activation, as assessed via surface EMG, of the agonist (biceps) and antagonist (triceps) muscles during a subsequent bout of eccentric exercise in the contralateral elbow flexors.

### 1.03. Research Hypotheses

1. Unilateral eccentric exercise performed with MVF will lead to a smaller reduction in maximal voluntary isometric contraction (MVC) force, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.

2. Unilateral eccentric exercise performed with MVF will lead to a smaller reduction in elbow flexor range-of-motion (ROM), compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
3. Unilateral eccentric exercise performed with MVF will lead to less delay-onset muscle soreness (DOMS), compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
4. Unilateral eccentric exercise performed with MVF will lead to greater biceps EMG amplitude, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
5. Unilateral eccentric exercise performed with MVF will lead to reduced triceps EMG amplitude, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.

**1.04. Null Hypotheses**

1. Unilateral eccentric exercise performed with MVF will lead to no changes in maximal voluntary isometric contraction (MVC) force, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
2. Unilateral eccentric exercise performed with MVF will lead to no changes in elbow flexor range-of-motion (ROM), compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
3. Unilateral eccentric exercise performed with MVF will lead to no changes delay-onset muscle soreness (DOMS), compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.

4. Unilateral eccentric exercise performed with MVF will lead to no changes in biceps EMG amplitude, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.
5. Unilateral eccentric exercise performed with MVF will lead to no changes in triceps EMG amplitude, compared to no MVF, when subsequent eccentric exercise is performed 1 week later in the contralateral arm.

**1.05. Significance**

The results of this study will provide more insight into the repeated bout effect and cross education. It will examine the magnitude of the cross education of the RBE to the contralateral limb with and without the use of mirror visual feedback, which may help elucidate what potential mechanisms of the "mirror neuron system" also overlap in cross education or vice versa. These findings can prove useful to general, athletic, and clinical populations who temporarily are unable to use one side of the body as this crossover effect can help preserve protection, recovery, and strength.

**1.06. Delimitations**

The findings of the study apply only to healthy men aged 18-35 years old.

The participants must not be taking any prescription pain medication(s) that interfere with neuromuscular function.

The participants must not be taking any OTC pain medications (NSAIDS) currently.

The participants must have no history of muscle disorder/ dysfunction / surgery interfering with performance of high-intensity eccentric exercise of the elbow flexors.

The participants must not be taking any performance enhancing supplements or drugs.

The findings will only apply to untrained men who have not actively resistance trained their arms for the past 6 months.

## 1.07. Limitations

A nonrandom sample will be used as participants were volunteers from the University of Oklahoma and the surrounding counties.

Participants will be instructed to continue to follow their normal diet, but this will not be monitored.

Participants were instructed to avoid all resistance exercise outside of that performed in the study for the duration of the study. This was confirmed via self-report, but researchers were not able to fully monitor adherence.

Due to available equipment (KinCom isokinetric dynamometer), it was impossible to completely isolate biceps muscle.

## 1.08. Assumptions

Participants gave maximal effort during all testing sessions.

Reliability and validity of all testing protocols was established in prior research

Participants were truthful in health screening

Participants were truthful in reporting on muscle soreness

Participants adhered to instructions and avoided resistance training outside of the lab.

## 1.09. Operational definitions

**Repeated Bout Effect (RBE)**: The Repeated Bout Effect is the intrinsic neural and physical adaptation of the skeletal muscle to attenuate muscle damage from future exercise

**Muscle Damage:** Occurs from unaccustomed exercise and results in a defined set of symptomatic, systematic, and histologic changes in the skeletal muscles

**Delayed Onset Muscle Soreness (DOMS):** Moderate to severe muscle soreness usually experienced 2 to 3 days after an bout of eccentric exercise and can last up to 5-7 days

**Ipsilateral RBE –** Measured repeated bout effect on the same limb (Control)

**Contralateral RBE –** Measured repeated bout effect on the opposite limb

**Mirror Neuron System (MNS)-** The Mirror Neuron System (MNS) consists of a complex network of neurons across the lobes of the brain and provides a neuroanatomical basis for the development of motor learning and skill acquisition by observing actions and imitating an act (Howatson et al., 2013).

**Mirror visual feedback** – Illusionary mirror visual feedback is provided by placing a mirror in the midsagittal plane, with the mirror reflection of one limb superimposed over the contralateral, hidden limb (Carr et al., 2019)

**H-Reflex –** Reflexive jerk movement of the antagonistic muscle. Contains oligosynaptic components (Ia afferents) and provides inhibitory input on the agonist muscle (Fisher, 2014).

# CHAPTER 2: LITERATURE REVIEW

## 2.01. Outline

As mentioned in chapter 1, this study will be looking at magnitude of the cross education of the repeated bout effect after unilateral eccentric exercise with and without the use of mirror visual feedback. This literature review will be discussing the mechanisms of action for DOMS, DOMS effect on performance, the repeated bout effect, cross education & mirror visual feedback, and cross education of the RBE. It will also review literature on the effect of the menstrual cycle on muscle damage and recovery from muscle damage. Because we are using female participants, we will be controlling for the menstrual cycle by performing the experimental testing period during the luteal phase of the menstrual cycle. Sources were searched using several databases available from the University of Oklahoma. The main databases used were google scholar, MEDLINE (EBSCO), PubMed, and SportDiscus. Keywords used were: Muscle Damage, DOMS, Eccentric Exercise, Repeated Bout Effect, Cross Education, Cross-over effect, Mirror, Mirror visual feedback.

## 2.02. Muscle Damage and Delayed-Onset Muscle Soreness

DOMS is described as the delay of muscle soreness in the first 24 hours after exercise. It can usually be described as an aching pain in the muscle along side with muscle stiffness and tenderness. The sensation of pain increases when mechanical stimuli such as pressure, stretching, or contractions is applied to the muscle (Tiidus, 2008). The intensity of DOMS peaks from 24 hours to 72 hours, and completely subsides by the $5^{th}$ or $7^{th}$ day postexercise. DOMS has often been associated with muscle damage as a result of eccentric contractions (Armstrong, 1984). It has been shown that eccentric contractions where the muscle is lengthened produces the greatest amount of DOMS versus isometric (at both short and long muscle lengths) and concentric

contractions. It has been show that pure concentric contractions is not enough to induce DOMS, however, when people train concentric contractions they will also unintentionally perform eccentric contractions, especially when the person has reached muscle fatigue (Tiidus, 2008).

There are several theories proposed to help explain the mechanisms of DOMS. It was first proposed as the "Damage Theory" in 1902 where researchers concluded that DOMS was the result of ruptures within the muscle (Hough, 1902). However, it is better known now that "ruptures in muscle fibers" are generally not associated with DOMS. What researchers discovered to be associated with DOMS is disruptions of myofilaments, especially at the Z-disc, which is characterized by broadening, streaming, or smearing of the Z-disc structure, all of which can increase mechanical sensitivity of muscle nociceptors (Tiidus, 2008). It is also possible that damage to the connective tissues such as the perimysium and endomysium could be related to DOMS. Damage to the muscle and disruptions of the myofilaments has also been shown to produce a subsequent inflammatory response, which could lead to the sensitization of muscle nociceptors over time (Smith, 1991). Instead of viewing all of these mechanisms separately, it is highly likely that both damage to the muscle and its connective tissue, as well as the subsequent inflammatory response are associated with DOMS (Cheung et al., 2003). The magnitude of muscle damage induced by eccentric contractions is affected by a variety of factors. This includes intensity, velocity, number of contractions, muscle length, muscle group, age, sex, and exposure to eccentric loads in daily activity. They found that there was greater muscle damage when using a higher intensity, faster velocity, larger repetitions, and those with longer muscle lengths. The arm muscles are also more susceptible to muscle damage than the legs.

Muscle damage can only be verified by physical morphological examination; however these evaluations and procedures are difficult to perform, therefore, it is more common to see indirect markers as measurements for muscle damage. There are also several ways to measure muscle damage through subjective and objective measures. Several scales have been used to perceptually measure or quantify muscle soreness including VAS, numerical rating scales, and verbal rating scales. However, it is important to note that soreness and pain sensation vary among individuals as it is a very subjective measure. Perception of pain can vary greatly within and between individuals given their mood, health, and hormonal status. With DOMS, we also commonly see a loss of muscle function with decreases in muscle strength and range of motion. Decreases in maximal voluntary contraction (MVC) is considered the best way to quantify muscle damage (Warren et al., 1999). This can be measured by looking at the decrease in isometric strength over a period of time (post-exercise and over course of days or weeks) and the decrease in eccentric torque throughout the eccentric bouts. Muscle damage is also assessed via increases in muscle-specific proteins in the blood such as creatine kinase (CK) and myoglobin (Clarkson et al., 1992). All these measurements are often correlated with muscle damage, however some have a different time course. Muscle soreness and range of motion is more affected 2 to 3 days postexercise, however muscle strength has been shown to drop immediately. Because of the different time course, it is hard to correlate DOMS with the other indicators or symptoms of muscle damage. It has also been shown that even though resistance trained individuals have reduced muscle damage, the peak level of soreness rated does not differ from untrained individuals. So, trained individuals can feel just as sore, but with significantly much less muscle damage. It has also been shown that DOMS is not necessarily a warning sign to cease all physical activity. When performing submaximal exercise, it was observed that DOMS

was significantly reduced temporarily. This shows that although maximum strength may be reduced, the muscle is still able to function as normal when continually performing activity. A study looking at 2 strenuous eccentric exercise bouts within 2-3 days (Chen & Nosaka, 2006) discovered that a 2nd high intensity eccentric exercise during the early recovery stage does not exacerbate muscle damage and does not influence the recovery process, supporting the idea that DOMS is not a signal to the body to cease exercise.

**2.03. Repeated Bout Effect**

Unfamiliar eccentric exercise results in muscle damage, which results in individuals receiving DOMS. However, this process has been shown to have a protective effect. Following recovery from the initial bout of eccentric exercise, individuals will exhibit protection against muscle damage during the next bout of maximal eccentric exercise. This phenomenon has been termed as the repeated bout effect (McHugh, 1999, 2003). This effect shows a decrease in muscle soreness, faster recovery of strength, decreased muscle stiffness, and decreased muscle swelling. There are several factors that will affect the magnitude of the RBE as well as several ways that the RBE can occur. First, the effect of the RBE is greater with increases in intensity. We see this in a study where they had participants perform either maximal, 80%, 60%, or 40% eccentric elbow flexor exercise. The greater the intensity, the larger the RBE. However, it has also been shown that severe muscle damage is not a prerequisite for the RBE. The RBE effect can be elicited by submaximal eccentric exercise. It was reported that 40% ECC repeated every 2 weeks for four times was able to elicit the same magnitude of protective effect as one bout of maximal ECC. Maximal voluntary isometric contractions at long muscle lengths have also been shown to elicit a RBE. It was also reported that 2 or 6 maximal eccentric repetitions was able to confer a protective effect. The 6 repetition was able to provide a similar magnitude of protection

when compared to 24 maximal eccentric repetitions even though it produced less muscle damage. Muscle length also plays a role in RBE. A study looking at a long starting muscle length versus a short starting muscle length moving for the same range of motion saw that the short starting muscle length was able to produce a partial RBE (~50%) even though it produced much less muscle damage (Hyldahl et al., 2017).

In recent literature it is accepted that the possible underlying mechanisms for the RBE are due to neural adaptations, muscle-tendon complex behaviors, extracellular matrix structure remodeling, and the modified inflammatory response. This is built on the theories that McHugh (1999; 2003) presented as the possible mechanisms for the RBE. Previous studies have shown neural adaptations associated with the RBE. After a bout of maximal eccentric exercise, it has been shown that there is an increase in motor unit synchronicity and also a shift of recruitment to slow-twitch motor units during the second bout of eccentric exercise (McHugh, 2003). Using intramuscular EMG recordings, it was reported that motor unit synchronization increased up to 7 days after the eccentric exercise bout (Dartnall et al., 2007). It is possible that this increase in activation of slow twitch fibers to produce the force necessary to perform the movement is able to attenuate the muscle damage as slow-twitch muscle fibers are much less likely to experience muscle damage (McHugh, 2003). Also, the nervous system may be able to better distribute mechanical constraint over a greater motor unit sample during submaximal eccentric exercise. However, the ability to produce more force due to greater motor unit synchronization can potentially make the muscle more susceptible to damage due to the greater overall mechanical tension on the fibers. It has also been shown that eccentric contractions have a unique activation strategy that does not follow the same size principle that concentric contractions as the central nervous system is unable to maximize motor unit recruitment and discharge rate in subjects who

are unaccustomed to eccentric exercise. It has also been shown that volitional drive from the supraspinal centers and transmission efficiency in the Ia afferent synapses increased after training, meaning that eccentric-induced neural responses could possibly increase the alpha motor neuron excitability in the spinal cord or decrease presynaptic inhibition of Ia terminals (Kidgell et al., 2015). Similarly, in a study researching the neural changes at the muscle by looking at the coactivation of antagonist muscles during the 1st and 2nd bout of eccentric exercise, they found that during the 2nd bout of maximal eccentric exercise that there was less coactivation of the antagonist muscle, resulting in more total force being able to be produced during a max effort and less total force required to move an identical external load (Hight et al., 2017). With continual resistance training using eccentric exercise, it has been shown that there are increases in spinal motor neuron excitability, decreased presynaptic and postsynaptic inhibition, and elevated descending motor drive (Lepley et al., 2017; Aagaard, 2018).

Another possible theory for the RBE are the muscle-tendon complex behaviors and adaptations that may occur after eccentric training. A study has shown that the addition of sarcomeres in series has been shown to reduce mechanical strain to the muscle fibers (Proske et al., 2001), however sarcomere remodeling cannot fully explain the RBE. Tendon compliance such as fascicle length may also play a role in the protection of muscle damage. It has been shown that muscle fascicle length is less prone to elongation during the 2nd eccentric bout, which has shown to lead to less DOMS (Lau et al., 2015). There are no direct studies examining tendon adaptations after a bout of eccentric exercise, and more research needs to be conducted on investigating muscle-tendon behavior changes as well as in conjunction with an neural or peripheral adaptations. In addition, extracellular matrix structural remodeling (ECM) is another possible mechanism that focuses on the structure of the muscle fiber or its tendons. This ECM is

the complex network of collagen and glycoproteins that envelop single muscle fibers. One of ECM's primary function is to buffer myofibers from mechanical strain by increasing passive tension. Eccentric exercise as well as electrical stimulation has been shown to increase the ECM restructuring rate, however it seems likely to occur some time beyond 2 days postexercise and can last up to 4 weeks (Hyldahl et al., 2017). After eccentric exercise, the muscle first undergoes a de-adhesion process causing sarcomere disruption and membrane damage, however after 3 days, the muscle sill have an increased rate of collagen expression and TGF-B signaling, resulting in a diminished de-adhesion process after the 2nd bout (Hyldahl et al., 2015).

The RBE may also be attributed to a modified inflammatory response adaptation after a bout of eccentric exercise. There is some evidence of a blunted inflammatory response after the 2nd eccentric bout in mice (Pizza et al., 2002, Hyldahl et al., 2017), however it was found that there was a greater inflammatory response after the 2nd eccentric bout in humans (Deyhle et al., 2016). It is suggested that this increase in certain markers such as cytokines, macrophages, and T-cells may play a role in muscle regeneration, however there is no clear evidence or study directly looking at this effect. Hyldahl et al. (2017) suggest that enhanced acute inflammatory response may help speed up the recovery of the muscle, however, they also state it could simply be a reduction of muscle damage and more that more research needs to be conducted looking into this question.

To summarize, we see that through repeated bouts of eccentric exercise, muscles are able to produce a protective adaptation protecting themselves from muscle damage and DOMS from future exercise. It has been shown that there are multiple intensities or specific regimens to reproduce these adaptations, however, cease of exercise longer than 8 weeks will show a

reduction in the RBE. Again, it is unlikely that it is just a single mechanism that fully explains the RBE, but rather the culmination of each model that fully contributes to the RBE.

## 2.04. Cross Education

**“**Cross education”, the “cross over effect”, or the “cross-training effect” is the inter-limb phenomenon where adaptations in one limb will confer to the contralateral limb. Specifically, the increase in muscle control and voluntary force generation in the untrained, contralateral, homologous limb after a bout of unilateral training (Scripture, 1894; Lee & Carroll, 2007; Manca et al., 2021). Cross education has been extensively studied in literature for the past century and the main characteristics have been identified. Cross education can occur in both upper and lower limb muscles as well as small intrinsic muscle to gross large muscles, and does not appear dependent on direct or indirect corticospinal projections (Lee & Carroll, 2007). There is some evidence that there is a cross over but of less magnitude to synergic, nonspecific muscles (Mason et al., 2018). Cross education can occur at any age and is not gender specific (Zhou. S, 2000), however, it has been shown that the magnitude of cross education seems to decrease with age (Hinder et al., 2011). Cross education can occur through voluntary contractions, electrical stimulation (Hortobagyi et al., 1999), or mental practice of unilateral contractions (Yue & Cole, 1992; Ranganathan et al., 2004). Cross education can occur with various modalities such as isometric contractions or dynamic contractions, however, the strength gain is greatest when the same movement task is performed (Lee & Carroll, 2007). In order for cross education to occur, there needs to be an absence of muscle activity in the untrained muscle during the unilateral exercise and when there is no muscle hypertrophy occurring in the untrained limb (Lee & Carroll, 2007). Cross education also has value in the purely clinical setting as it has been demonstrated in patients with neurological disorders such as stroke and multiple sclerosis.

Previously, the magnitude of strength increase in the untrained limb was determined to be about 8% (Munn et al., 2004; Carroll et al., 2006) and can also be defined as the cross education of strength is normally about a 52% of the strength increase observed in the trained limb, however, that magnitude can vary greatly with a range of no significant effect to 77% after voluntary training (Farthing 2009), and up to 104% after electrical stimulation (Hortobagyi et al., 1999). In recent literature, there has been shown to be an even greater cross education effect. In a recent meta-analysis looking at the cross education of muscular strength it was calculated that there is a greater than 8% (3.8% for the upper untrained limbs and +10.4% for the lower untrained limb) increase in strength after unilateral training. After looking at 731 subjects, there is approximately a strength increase of 11.9% (9.4% for the upper untrained limbs and 16.4% for the lower untrained limbs (Manca et al., 2017). Contraction type also plays a role as eccentric and isometric contractions have been shown to induce significantly greater contralateral gains in strength than isometric contractions (Hortobagyi et al., 1997; Manca et al., 2017; Frazer et al., 2018). Eccentric contractions have also been shown to reduce intracortical inhibition and increase corticospinal excitability compared to concentric training for the untrained limb (Kidgell et al., 2015).

Chronic unilateral motor activity affects motor output of the contralateral homologous muscle. However, this training does not contribute to muscle hypertrophy in the unused contralateral limb. This indicates an organizational and functional role for the central nervous system in cross education. Though it is well accepted that neural mechanisms are the primary reason that gives rise to the cross education effect, it is poorly understood and there is some debate on which theoretical models and neurophysiological evidence is acceptable or accurate. Imaging techniques such as fMRI and positron emission topography (PET) have improved the

ability to examine the human central nervous system, which has provided some insight into the neural mechanisms of cross education. TMS has also been able to provide a way to determine excitatory and inhibitory synaptic activity of the motor cortex and corticospinal tract. As stated in the earlier subsection discussing the RBE, unilateral training can induce changes to the efficacy of the Ia neurons in the corticospinal tract. This effect has been shown to occur bilaterally in the corticospinal tract and show increased activity in the M1 (Frazer et al., 2018). There is also evidence that suggests regions functionally connected to the M1 also receive increased blood flow and activity during unilateral resistance exercise, and these structures have structural white-matter connections homologous in the opposite cerebral hemisphere (Ruddy et al., 2017). This could mean there is a structural basis for the neural mechanisms involved in the crossover from unilateral training. A study looking at neural activity of the motor cortex showed that repetitive TMS applied to the supplementary motor area abolished the cross-transfer of a motor-learning task to the untrained limb, showing support for a structural basis (Perez et al., 2007). A recent study confirmed that there is a increased structural connectivity in the bilateral supplementary motor areas and that motor performance improved in association with the increase in functional connectivity between the right and left supplementary motor area. This further supports that there is a level of engagement in the interhemispheric pathways and that the level of structural connectivity influences the magnitude of cross education (Ruddy et al., 2017). However, a meta-analysis analyzing 10 studies on the crossover of neurological adaptations to the untrained hemisphere of the motor cortex saw that only 6 of the 10 studies reported a significant increase of cross education in activity in the untrained hemisphere. (Colomer-Poveda et al., 2021). These inconsistencies could demonstrate that the cross over effects may not rely solely on interhemispheric pathways and could occur at different portions of the motor cortex.

Unilateral injuries, oseteoarthritis, tendinopathy, fractures, stroke, cerebral palsy, etc. These types of injuries can lead to patients being immobilized in that limb for 2-6 weeks and even longer depending on the dysfunction. During this time, muscle stiffness, a reduction in range of motion, a reduction in strength, and atrophy can occur due to the inability to use the limb. Because of cross education's foundational reliance on neurophysiology, it has been identified as a strong potential rehabilitation strategy with the use of unilateral work when individuals are unable to use a limb due to neuromuscular dysfunctions or injuries. Studies have shown that when healthy individuals were induced limb immobilization, strength loss was attenuated with a cross education intervention, and some evidence of muscle sparing was observed as well (Frazer et al., 2018).

## 2.05. Mirror Neuron System

The Mirror Neuron System (MNS) consists of a complex network of neurons across the visual areas of the parietal, occipital, and temporal lobes of the brain and provides a neuroanatomical basis for the development of motor learning and skill acquisition by observing and imitating an act (Howatson et al., 2013). It was discovered by Giacomo Rizzolatti and colleagues (1996) when they observed that monkeys had a group of neurons of the premotor cortex fire when performing an action and also firing when observing the same action being performed by others. Brain imaging has shown this pattern in humans and that mirror neurons fire even while observing meaningless movements. Meaningful actions observed cause mirror neurons to fire in the frontal and temporal nodes of the MNS, and meaningless actions only result in firing of the frontal lobe (Rahjmohan & Mohandas, 2007). One of the main functions of the NMS this review will be focusing on is action understanding as mirror visual feedback and motor imagery are forms of action observation. There are three main hypotheses to explain the

phenomenon of action understanding are visual hypothesis, direct-match hypothesis, and generate and test model. The direct match hypothesis is based on the mapping of observed action on the individual's own motor representation of the observed action. This supports evidence that cortical structures involved with the actual execution of movement are also activated by the observation of that specific movement as well as visual input by action observation likely results in greater excitation of the system. It has been shown that motor imagery has been able to activate motor neurons involved in the imagined movement and also increase the H-reflex amplitude for both muscles (Gandevia, 1997). Continued research has also shown that motor imagery improve reflex response times and has a potent effect on the excitability of spinal reflex pathways (Li, et al., 2004; Grospretre et al., 2015)It is possible that there is overlap in the areas involved in the Mirror Neuron System and in cross-education. In a study comparing motor imagery and neuromuscular stimulation, they found that MI was an effective intervention to induce cross education. They suspect it to be due to the progressive neurological adaptation of activation of multiple cortical motor regions in the brain which can improve corticospinal neural drive such as the H-reflex (Bouguetoch et al., 2021).

## 2.06. Cross Education of RBE (Contralateral RBE)

It has been demonstrated in previous research that the cross-education of strength is greater in the contralateral limb when the ipsilateral limb is trained using eccentric contractions This suggests that the protective effects of the RBE is transferable from limb to limb. This was first shown in 2007 where researchers reported a CL-RBE after a single bout of maximal eccentric exercise, however, this magnitude was less than that of the ipsilateral limb (Howatson & Someren, 2007). This magnitude has varied in different studies, however, it seems that the CL-RBE falls somewhere between 40-60% of that of the ipsilateral RBE (Hyldahl, 2017). In a

recent study comparing the CL-RBE for different time intervals between two bouts (0.5h, 6h, 12h, 24h, 7d, 28d, or 56d) to the RBE by the same arm after 2 weeks, we see that a significant CL-RBE at 1, 7, and 28 days (Chen, 2016). However, the magnitude of the CL-RBE seems to decrease much faster with more time between bouts as the CL-RBE was greatest (70%) after 24 hours and decreased at 7 days (55%) and 28 days (36%). The CL-RBE was diminished by 56 days, indicating a much quicker decline in the RBE. They also saw that the CL-RBE at 7 days was approximately 50% when compared to that of the ipsilateral after 14 days.

As mentioned in the earlier subsection, we see that a modified inflammatory response may also play a role in contribution to the cross education of the RBE. It was observed that certain B cells that were activated after the 1st eccentric bout was attenuated after the 2$^{nd}$ eccentric bout. They explained that it is plausible that the attenuation of B cells is an upstream mechanistic pathway that is transferred to the untrained limb, possibly through neural adaptation. It may suggest the possibility that cellular adaptation in exercised muscle is homologous to the contralateral muscle (Hyldahl et al., 2017).

**2.07. Sex-related Differences in Muscle Damage**

Previously, there was controversy surrounding the sex differences in the development of and recovery from muscle damage. Based off intuition, one might believe that the differences in strength, mass, and hormones can lead to differences in exercise induced muscle damage and in the effect of the RBE, however, it has been shown that there are very minimal differences between men and women. Multiple studies have been done illustrating that there are no significant differences between men and women when looking at muscle soreness, isometric strength loss, and eccentric torque change after and during a bout of maximal eccentric exercise (Rinnard et al., 2000; Sayers & Clarkson et al., 2001; Hubal et al., 2008, Sewright et al., 2008;).

A meta-analysis looking at 24 studies found the only significant differences between men and women were in absolute eccentric torque and in levels of CK after exercise. However, when normalized to size, there was no differences in eccentric torque. They also found no differences in eccentric strength loss, isometric strength loss, and muscle soreness (Morawetz et al., 2020). The increase in CK in men could be due to larger muscle sizes and/or increases in work output. Inflammatory pathways for the marker CK seem to work differently between men and women, however, muscle damage and adaptations to eccentric exercise have often been shown to have no differences between sex.

As mentioned before, although there were observed differences in muscle damage between sexes, there is evidence that women may respond to exercise-induced muscle damage differently depending on what stage in the menstrual cycle that they are in and this may be attributed to the difference in hormone concentrations. A meta-analysis looking at 12 studies found that DOMS and strength loss is affected by MC phases in women. They found that the higher concentrations of sex hormones estrogen and progesterone during the luteal phase exhibited lower DOMS and strength loss between pre-exercise and post-exercise (Romero-Parra et al., 2021). To ensure consistency, women with a normal menstrual cycle were tested in the luteal phase of this study due to the time constraint of completing the required visits in a 2-week span.

## 2.08. Summary & Knowledge Gaps

This study attempts to explore the interventions, specifically mirror visual feedback, on its effects on the cross transfer of the RBE. As mentioned before in the subsections discussing cross education and the mirror neuron system, it has been shown that there is preliminary evidence that cross education is enhanced by mirror visual feedback. It has been suggested that

the structures implicated in cross-education have neuroanatomical commonality with those in the mirror neuron system. To the author's knowledge, there are no known studies looking at the cross education of the RBE with and without mirror visual feedback. Most studies conducted using mirror feedback have been on the cross education of strength or conducted in the clinical setting on those with neuromuscular dysfunction. In the modified delphi consensus, it was agreed upon that mirror feedback is a strategy to enhance the magnitude of cross education. However, the mechanisms of the RBE are multi-faceted and may or may not rely more on other non-neuroanatomical models such as the muscle-tendon complex, modified inflammatory response, or in the extracellular matrix structure remodeling. Due to it being multi-faceted, it could be possible that after a maximal bout of eccentric exercise, we do not see an enhancement of the cross education of the RBE in comparison to a group who is not using mirror feedback. This study can help determine if activation of the MNS through action observation and motor imagery enhances the magnitude of transfer of the cross education effect.

# CHAPTER 3: METHODOLOGY

## 3.01. Introduction

This study examined cross-education of the repeated bout effect with and without mirror visual feedback. This study mimicked the design and methodology from previous studies looking at the magnitude of cross-education of RBE. The novel aspect of this study was the inclusion of mirror visual feedback with the use of a mirror placed at the midsagittal line to create a mirror image "illusion" of the performance of bilateral contractions. Mirror visual feedback has been shown to enhance the cross-education of neural adaptation to single arm isometric/resistance training, but whether it would be similarly effective at enhancing the RBE has not been tested. This study included 2 experimental groups (Mirror vs. Non-Mirror) to examine the cross-education effect and 1 ipsilateral control group (the same arm was tested twice) for comparison.

## 3.02. Sample

A convenience sample was recruited by word-of-mouth and emails distributed to the Department of Health & Exercise Science and other departments at the University of Oklahoma. Participants were randomized into either the control, no mirror, or mirror group. Thirty-seven men and women consented to perform the study. However, 5 participants were not able to complete all testing sessions. Additionally, 4 participants were excluded from the data set as they did not exhibit significant muscle damage (defined as a decline in MVC force of ≥10% and/or self-reported soreness). This left a total sample size of n=28 (14 women and 14 men) who were used in analysis. The mirror group contained n=10, no mirror group contained n=12 and, the control group contained n=6. This sample size was estimated using data from previous studies (Chen et al., 2016) and should be sufficient to detect a difference in performance when using a two-tailed dependent-measures t-test at an alpha level of 0.05 and power of 0.80. Men and

women were included in the sample as no significant gender differences in maximal isometric strength loss and soreness after high-force eccentric exercise (Chen & Nosaka, 2006). A meta-analysis looking at sex-related differences after a single bout of maximal eccentric exercise saw that there were no differences between men and women in normalized eccentric torque, eccentric strength loss, nor muscle soreness (Morawetz et al., 2019). Women were tested during follicular phase of their menstrual cycle as perception of pain have been shown to vary across the cycle.

Participants were asked to refrain from exercise / vigorous activity and to maintain normal dietary habits as well as avoid any anti-inflammatory drugs (NSAIDS) or nutritional supplements during the experimental testing period. However, participants' activities and food intake were not recorded. Participants were instructed to drink plenty of water before and after exercise to avoid a possible risk of rhabdomyolysis, to refrain from alcohol consumption, and to avoid treatments of the exercise muscles during the study.

### 3.03. Inclusion Criteria

1. Male or Female between the ages of 18 and 35 years
2. Those with no resistance training in the arms in the past 6 months

### 3.04. Exclusion Criteria

1. Taking any prescription pain medication that interfere with muscle function.
2. Taking any OTC pain medications (NSAIDS)
3. History of muscle disorder / dysfunction
4. Taking any performance enhancing drug or supplement
5. Actively training elbow flexors
6. Surgeries preventing exercise

## 3.05. Experimental Design

This study used a pre-test/post-test-controlled design with 2 experimental groups and 1 control group. This study will consist of 10 total visits with the first 2 visits being the familiarization period and the last 8 visits being the experimental testing period.

The 2 experimental groups were the mirror group and non-mirror group, and both groups performed a bout of high-intensity eccentric exercise with their dominant arm, and then performed a similar bout with their contralateral arm 1 week later as this has been previously shown to provide the largest magnitude of CL-RPE (Chen et al., 2016). The control group performed high intensity eccentric exercise in the dominant arm and then repeated the same bout of exercise in the same limb 2 weeks later. Arm dominance was confirmed via self-report through a series of questions about arm dominance for specific activities. Muscle damage was assessed by measuring DOMS, MVC, and elbow ROM prior to and immediately following eccentric exercise, and 24, 48, and 72 hours following eccentric exercise.

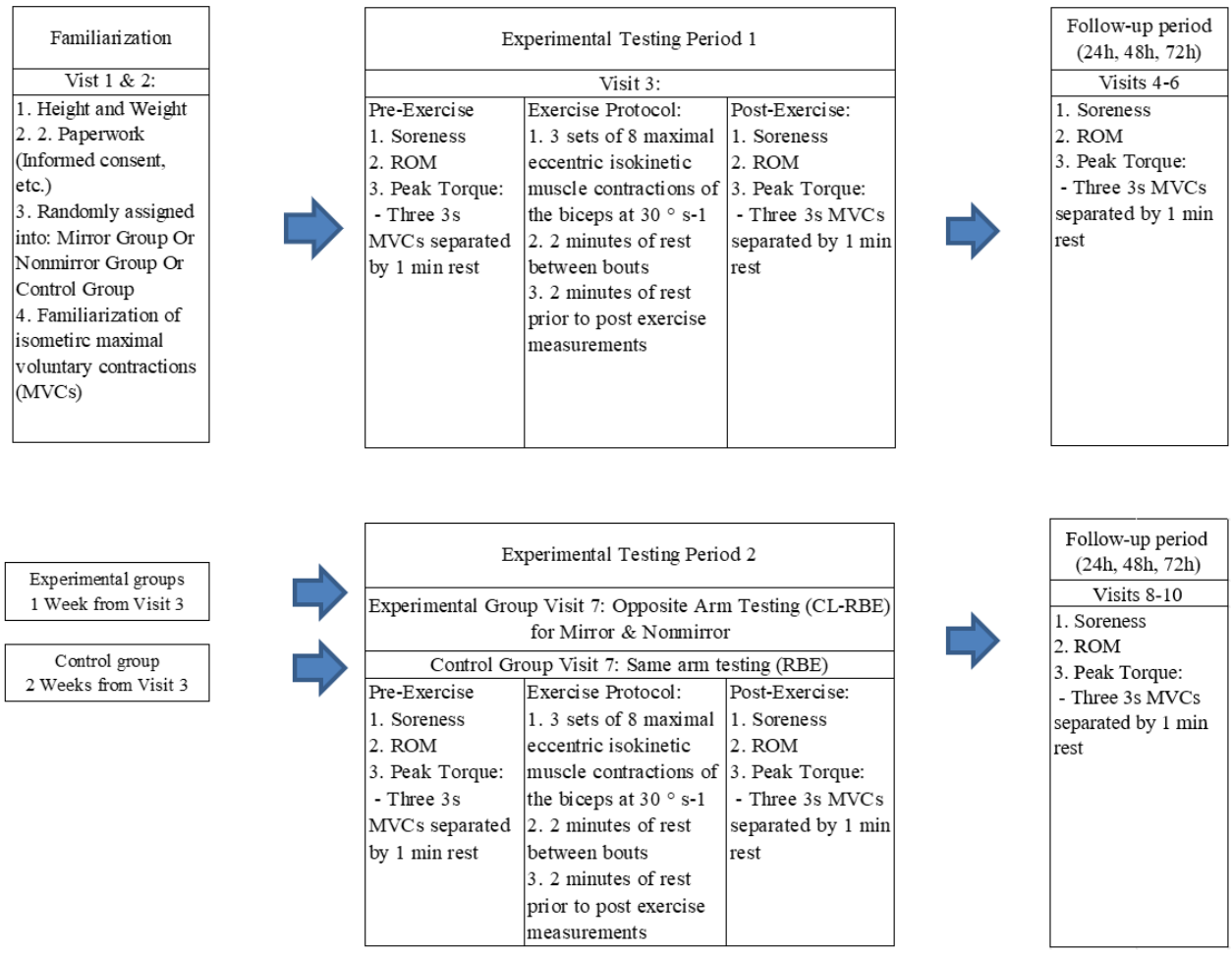



**Figure 1**- Study design of experimental timeline & measured outcomes

**Familiarization**

During the first visit the participants filled out the required paperwork which included an informed consent, HIPAA, menstrual cycle history, Physical Activity Readiness Questionnaire (PAR-Q), health screening form, and a rhabdomyolysis screening form. Once complete, body anthropometrics were measured and recorded. The participants were then familiarized with completing an isometric maximal voluntary contraction of the elbow flexors. Isometric maximal voluntary contractions (MVC) were performed on the KinCom Isokinetic Dynamometer (Isokinetic International, Chattanooga, TN, USA). Participants were set up on the KinCom with

an elbow joint angle of 90 degrees while using a neutral grip. Participants were instructed to contract as hard as possible for 3 seconds and then rest for 1 minute between bouts. They performed this at least 3 times until they were comfortable with the process of performing a MVC. On the second visit, participants again practiced the MVC protocol. Participants were then randomly assigned to be in one of the experimental groups (mirror vs. no mirror) or the control group (no mirror, same arm).

**Experimental Testing Period 1**

This Period consisted of experimental testing, which started with the 3rd visit, and contained the 3 follow-up visits (4 through 6). During the 3rd visit participants first performed a rating of muscle soreness in their biceps and the range-of-motion of the elbow was assessed. Participants then performed 3 isometric MVCs of the elbow flexors with 1 minute of rest between bouts. Once this was completed, the participant were set up on the KinCom to where the range-of-motion of the eccentric contraction began with the bicep being fully flexed and finished with the elbow at complete lockout/extension. They were then instructed how to perform the eccentric exercise protocol. The KinCom controlled the speed of the eccentric contraction by moving at a speed of $30^{\circ s^{-1}}$. As the KinCom pulled their elbow down from fully flexed to full extension, participants were instructed to resist the machine and pull as hard as they could while trying to flex their elbow using their biceps. Three sets of 8 repetitions of maximal eccentric contractions were performed in this manner. In the mirror feedback group participants were instructed to watch the contractions in the mirror so it appeared their contralateral arm was also performing the contractions. Participants received 2 minutes of rest between sets. During eccentric exercise EMG data of the biceps and triceps was collected. After exercise, the participants reassessed their muscle soreness, MVC, and elbow ROM.

Participants were required to return to the lab each day for the next 3 days (24, 48, and 72 hours) for visits 4-6. During these visits, participants reassessed their muscle soreness, performed MVCs, and had elbow range-of-motion reassessed. Those in the mirror and no mirror groups waited 7 days from the 3rd visit before beginning the next testing period. Those in the control group waited 14 days from the 3rd visit.

**Experimental Testing Period 2**

This period consisted of the 2nd experimental testing phase, which started with the 7th visit, and the follow up visits 8 through 10. Participants in the experimental groups (Mirror vs. Non-Mirror), conducted all measurements during this period on their contralateral arm while those in the control group performed all measurements in the same arm from period 1. During the 7th visit participants first performed a rating of muscle soreness in their biceps and had their range-of-motion of the elbow assessed. Participants then performed 3 isometric MVCs of the elbow flexors with 1 minute of rest between bouts. Once this was complete, the participant was set up on the KinCom to where the range-of-motion of the eccentric contraction began with the bicep being fully flexed and finished at to complete extension of the elbow. The KinCom controlled the speed of the eccentric contraction by moving at a speed of $30^{\circ s^{-1}}$. As the KinCom pulled their elbow down from fully flexed to full extension, participants resisted the machine as hard as they could by trying to flex their elbow using their biceps. Again, 3 sets of 8 repetitions of maximal eccentric contractions were performed. Participants received 2 minutes of rests between sets. EMG data of the biceps and triceps of the working arm were collected during this time. After exercise, muscle soreness, MVC, and elbow ROM was reassessed.

Participants then returned to the lab each day for the next 3 days (24, 48, and 72 hours) for visits 8-10. During these visits, participants again rated muscle soreness, performed MVCs, and had their elbow ROM reassessed.

## 3.06. Experimental Procedures

### Isometric Maximal Voluntary Contraction

Three MVCs of the elbow flexors were then performed with the elbow set at an angle of 90 degrees of flexion. One minute of rest between contractions. Strong verbal encouragement and biofeedback of force output were provided to aid in participants giving a maximal effort. The highest of the 3 efforts was considered the MVC for that time point and used in analysis.

### Maximal Eccentric Exercise Protocol

This protocol consisted of performing 3 sets of 8 repetitions of a maximal effort eccentric bicep curl. Using the KinCom software, full extension of the elbow (0°) was determined for each participant as the stop angle and full flexion (varied based upon individual anatomy) was set as the starting point. Participants were instructed to resist the dynamometer by contracting their elbow flexors with maximal effort as the dynamometer lever arm extension pulls their arm down to full extension, creating an eccentric contraction. Each repetition was performed at 30°/s. Strong verbal encouragement was provided as a visual feedback of the force produced to aid in providing a maximal effort. The dynamometer lever arm extension passively returned the arm to the flexed start position upon completion of each contraction. A 2-minute rest period was administered between sets.

### Mirror Visual Feedback

Participants in the mirror group performed the maximal eccentric exercise protocol with a mirror placed directly on their non dominant arm’s axilla, bisecting where the shoulder joint and

chest meet. This was to create a mirror image illusion effect where it appeared the individual was performing bilateral eccentric bicep curls. The mirror was held by a researcher and clear vision of the mirror and its illusion effect was confirmed by the participant. The mirror itself was used as a way to actively hide the non-dominant arm and participants were also instructed to perform as little movement with their non-dominant arm.

**Electromyography (EMG)**

During MVC and eccentric contractions on testing days 3 and 7, bipolar surface EMG signals were recorded from the biceps brachii and triceps brachii muscles using a BioNomadix dual-channel wireless EMG system (Biopac, Goleta, CA). A pair of silver-silver chloride EMG electrodes (Biopac, Goleta, CA) were placed ~16 mm apart over the belly of the biceps brachii and over the lateral head of the triceps brachii. A reference/ground electrode was placed over the elbow and the wireless sEMG system was secured around the forearm with a velcro strap.

Surface EMG recordings were analyzed using the Biopac AcqKnowledge software (version 4.4). The raw EMG signals from the biceps brachii and triceps brachii were collected at a sampling rate of 2000 Hz and band-pass filtered at 10 Hz and 500 Hz. The raw EMG signals were full-wave rectified using root-mean squared (RMS) averaging with a time constant of 30 ms to determine amplitude during contraction. The mean RMS amplitude was taken from the middle 2 seconds of each eccentric contraction for both muscle groups. Mean RMS values from each eccentric contraction were normalized and expressed as a percentage of the mean RMS values from biceps brachii during biceps MVC and during a triceps MVC.

**Elbow ROM**

The range-of-motion of the elbow joint was determined as the difference between 2 elbow joint angles—flexed angle (FANG) and relaxed angle (RANG). Briefly, a plastic

goniometer was placed over the axis of rotation of the elbow. Participants were then instructed to maximally voluntary flex their elbow to determine FANG. The stationary arm of the goniometer was aligned with the humorous and should joint while the measurement arm was rotated so it aligned with the ulna and wrist. For RANG, the stationary arm remained in place and participants were instructed to relax their elbow fully. ROM was calculated as RANG-FANG.

**Muscle Soreness**

Muscle soreness of the elbow flexors were quantified using a 0-100mm visual analog scale with "0" indicating "no pain at all" and "100" indicating the worst pain imaginable. The participants were instructed to perform a bicep curl using a dumbbell relative to their strength at about 50% 1RM (i.e., 5lbs used if 1RM was determined to be 10lbs). This was determined during the familiarization period. This determined weight was used and consistent for every visit. They were instructed to perform the concentric portion over 2 seconds and the eccentric portion over 2 seconds with complete range of motion to the best of their ability. Once complete, participants were asked to rate their muscle soreness.

## 3.07 Statistical Analysis

Values for torque isometric data, range of motion, and muscle soreness were analyzed using a three-way mixed model repeated measures ANOVA: 3 Conditions (Mirror vs No Mirror vs Control) x 2 Bout (Bout 1 vs. Bout 2) x 5 Time Points (Pre, immediately post, 24hr, 48hr, and 72 hr post). A three-way RMANOVA (Condition(3) x Bout(2) x Contraction(24) was conducted to examine differences in EMG between bouts and ipsilateral and contralateral mirror or no mirror protocols. Given the importance of the comparison between Bout 1 and Bout 2 in each group, separate 2 (bout) x 4 (time) repeated measures ANOVAs were performed to determine if a RBE occurred. Additionally, a "Protection Index" (Chen et al. 2016) was calculated for each

dependent measure at each time point. The was done by calculating the percent difference from Bout 1 to Bout 2 (with positive values representing smaller changes; thus protection from muscle damage). Maulchy's sphericity test was used to check homogeneity of covariance for all ANOVA analysis. Any violations of the assumption of sphericity were corrected using the Greenhouse-Geisser adjustment. A significance level of $p \leq 0.05$ was established. All analyses were performed using SPSS Ver. 28.0.

# CHAPTER 4: RESULTS

## 4.01. Sample

There was a total of 28 participants included in the data set. There were 6 in the control, 10 in the mirror, and 12 in the no mirror groups. The mean ± SD of age, height, weight, and pre-exercise MVC (Bout 1&2) for each condition was calculated. These descriptive statistics can be found in Table 1.

**Table 1** - Descriptive statistics & Pre-Exercise MVC (mean ± SD)

| Condition | Control (N=6) | Mirror (N=10) | No Mirror (N=12) |
|---|---|---|---|
| Sex (M/F) | 3 M 3 F | 3 M 7 F | 6 M 4 F |
| Age (Yrs) | 23 ± 3 | 22 ± 3 | 23 ± 4 |
| Height (In) | 65.50 ± 4.95 | 64.00 ± 4.69 | 65.83 ± 3.97 |
| Weight (Lbs) | 143.83 ± 37.87 | 135.10 ± 17.97 | 146.08 ± 30.79 |
| Bout 1 Pre-MVC (N*m) | 139.5 ± 59.45 | 128.90 ± 21.44 | 147.67 ± 36.91 |
| Bout 2 Pre-MVC (N*m) | 135.00 ± 50.90 | 120.60 ± 24.44 | 127.92 ± 32.78 |

## 4.02. Maximal Isometric Strength

The results of the three-way (Condition [Mirror, No-Mirror, Control] X bout [Bout 1, Bout 2] x time [iPost, 24hr, 48hr, 72hr]) repeated measures ANOVA for isometric MVC of the elbow flexors showed no significant three-way interaction ($p = 0.10$). The percent change in isometric MVC across all groups and time periods can be seen in Figure 3. The absolute data in isometric torque across groups and between bouts post-exercise can be seen in Table 2.

**Table 2** - Change in Biceps Isometric Strength Data by Condition & Bout (Mean ± SD) Post-Exercise

| Condition | Control | | Mirror | | No Mirror | |
|---|---|---|---|---|---|---|
| | Bout 1 | Bout 2 | Bout 1 | Bout 2 | Bout 1 | Bout 2 |
| Isometric MVC (N*m) | 98.08 ± 33.21 | 121.04 ± 49.55 | 86.20 ± 25.28 | 81.25 ± 17.64 | 89.67 ± 32.72 | 93.96 ± 29.46 |

Separate analysis comparing the change in MVC over time between Bout 1 and Bout 2 in each group was performed using a 2 (Bout) x 4 (Time Point) ANOVA and can be seen in Figure 4. For the control group, the bout x time interaction was not significant ($p = 0.15$). There was a main effect for time ($p = 0.007$) with 24, 48, and 72-HR time points differing from iPost ($p < 0.02$). There was also a main effect for bout ($p = 0.02$) with Bout 2 showing less change in MVC (indicating less EIMD) than Bout 1 (Fig 4A). In the Mirror group, the bout x time interaction was not significant ($p = 0.47$) nor was there a main effect for bout ($p = 0.70$). There was a main effect for time ($p = 0.03$) with the 24, 48, and 72-HR post time points differing from each other ($p < 0.03$). Similarly, in the No Mirror condition, the bout x time interaction was not significant ($p = 0.10$). However, like the control group there was a main effect for bout ($p = 0.009$) with Bout 2 demonstrating less change in MVC (reduced EIMD) than Bout1 and a significant main effect for time ($p = 0.02$) with values from 72-HR post exercise differing from all other time points ($p < 0.01$).

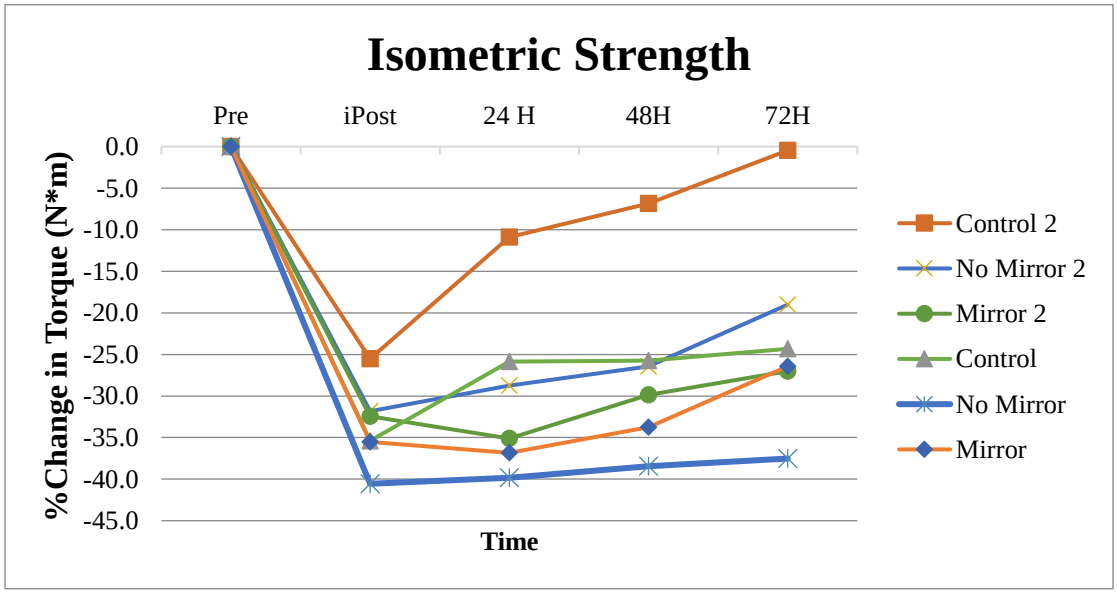
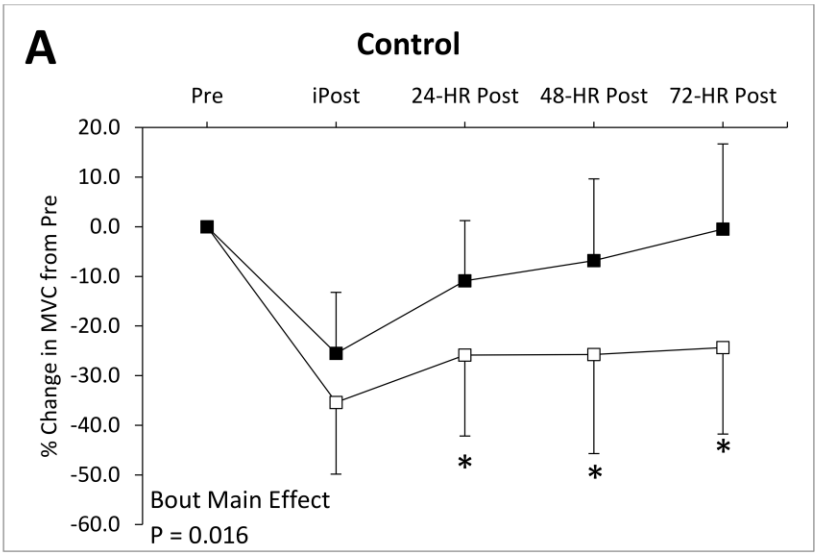
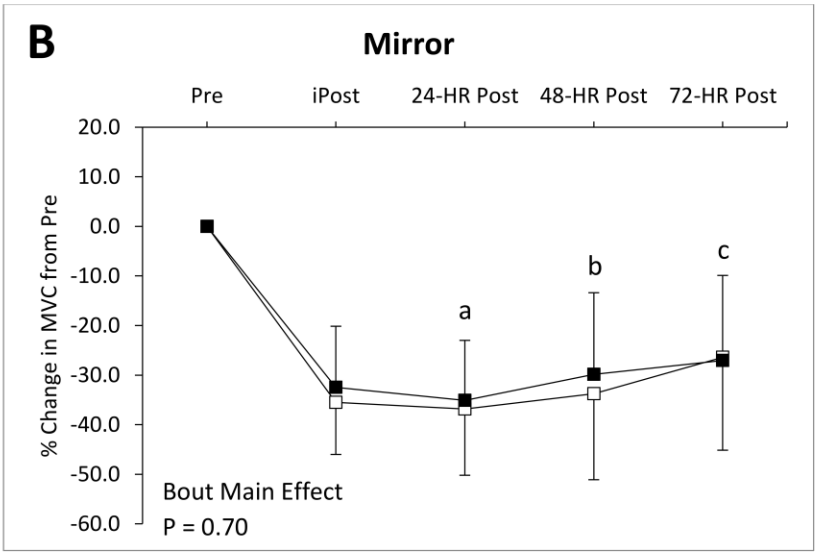



**Figure 2** -Maximal isometric torque before and after (post, 24H, 48H, & 72H) repeated bouts of eccentric exercise. Values are means; SD are not shown for clarity.


A
Control
Pre
iPost
24-HR Post
48-HR Post
72-HR Post
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
% Change in MVC from Pre
*
*
*
Bout Main Effect
P = 0.016


B
Mirror
Pre
iPost
24-HR Post
48-HR Post
72-HR Post
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
% Change in MVC from Pre
a
b
c
Bout Main Effect
P = 0.70

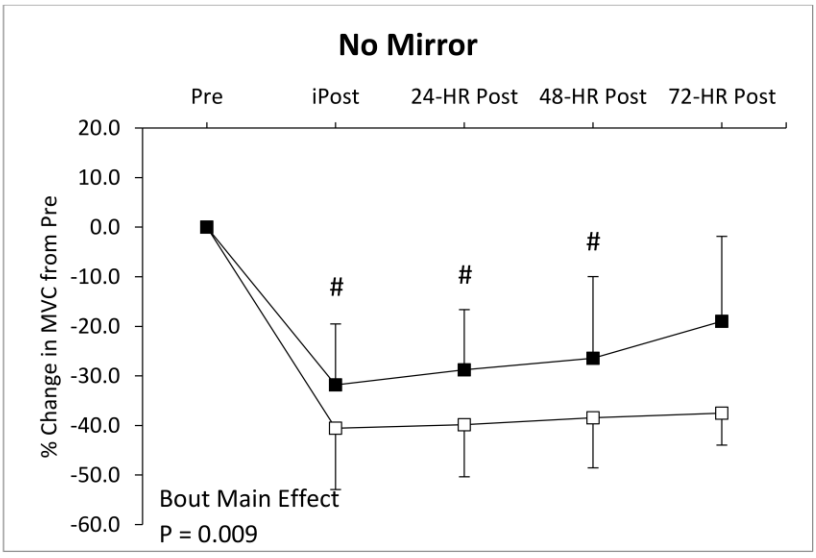

No Mirror
Pre
iPost
24-HR Post
48-HR Post
72-HR Post
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
-50.0
-60.0
% Change in MVC from Pre
#
#
#
Bout Main Effect
P = 0.009

**Figure 3** – Separate group analysis comparing the change in MVC over time (Post, 24H, 48H, 72H) between Bout 1 and Bout 2. A significant effect of bout can be seen in the Control group (A) and No Mirror Group (C)

The "protection index" for change in MVC between bouts can be seen in Figure 5. The group x time interaction was not significant (p = 0.10). Nor was there a significant main effect for condition (p = 0.11). There was a main effect for time (p = 0.045), with a larger average protection index at 72-HR post exercise compared to iPost (p = 0.02).

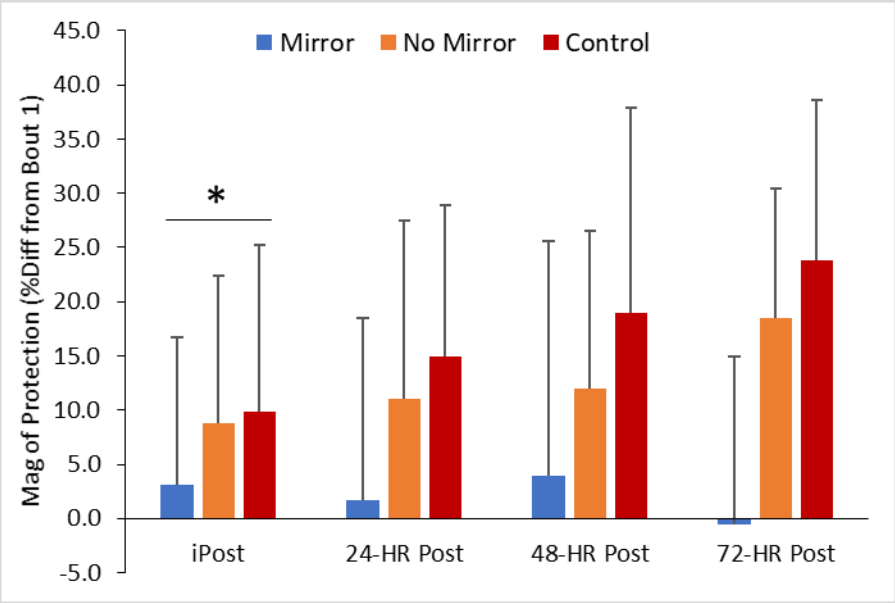



**Figure 4** -Magnitude of protection in maximal isometric torque within each group between bouts after repeated bouts of eccentric exercise. (*) denotes a significance between iPost and 72-HR post with larger protection index at 72-HR post (p=0.02)

## 4.03. Range of Motion

The results of the three-way (Condition [Mirror, No-Mirror, Control] X bout [Bout 1, Bout 2] x time [iPost, 24hr, 48hr, 72hr]) repeated measures ANOVA for ROM of the elbow flexors showed no significant three-way interaction (p = 0.35). ROM was all groups, all

conditions, and all time points can be seen in Figure 6. Absolute values for ROM across groups and between bouts post-exercise can be found in Table 3.

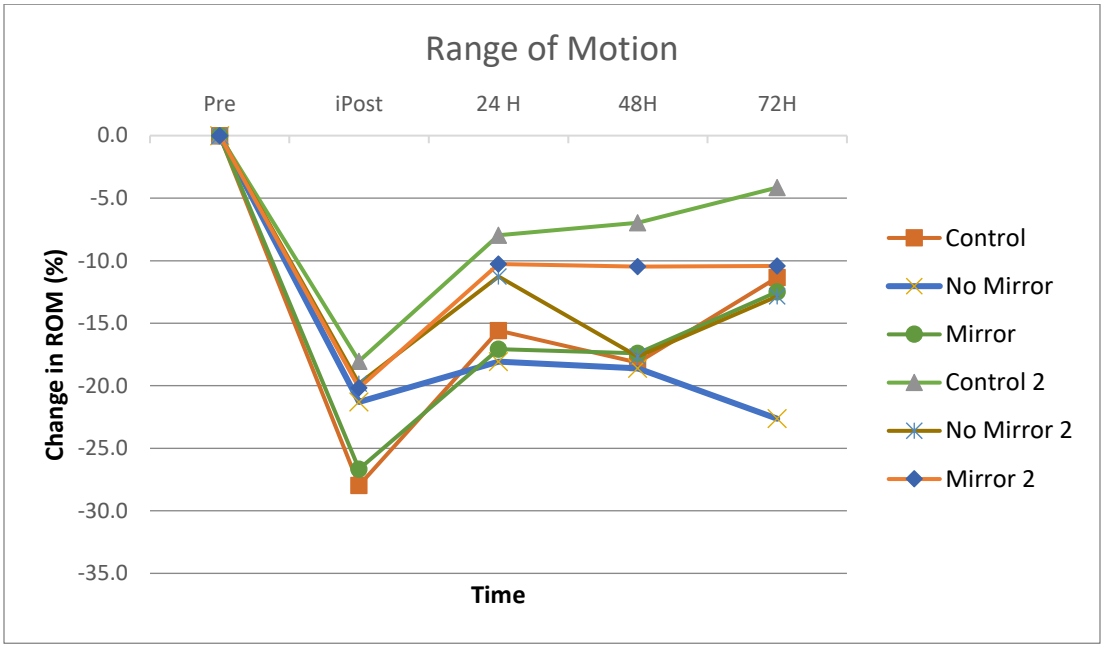



**Figure 5** - Percent Change in Range of Motion before and after (Post, 24H, 48H, 72H) repeated bouts of eccentric exercise. Values are means; SD not shown for clarity.

Separate analysis comparing the change in ROM over time between Bout 1 and Bout 2 in each group was performed using a 2 (Bout) x 4 (Time Point) ANOVA and can be seen in Figure 7. For the control group, the bout x time interaction was not significant ($p = 0.43$), nor was there a main effect for time ($p = 0.06$) or bout ($p = 0.47$; Fig 7A). In the Mirror group, the bout x time interaction was not significant ($p = 0.55$) nor was there a main effect for bout ($p = 0.26$) or time ($p = 0.07$; Fig 7B). Similarly, in the No Mirror condition, the bout x time interaction was not significant ($p = 0.32$), and there was no main effect for time ($p = 0.49$) or bout ($p = 0.49$; Fig 7C).

**Table 3 -** Change in Range of Motion by Condition & Bout (Mean ± SD) Post-Exercise

| Condition | Control | | Mirror | | No Mirror | |
|---|---|---|---|---|---|---|
| | Bout 1 | Bout 2 | Bout 1 | Bout 2 | Bout 1 | Bout 2 |
| Range of Motion (°) | 87.42 ± 17.87 | 94.04 ± 26.91 | 85.60 ± 18.57 | 88.25 ± 20.49 | 77.96 ± 22.78 | 85.83 ± 20.67 |

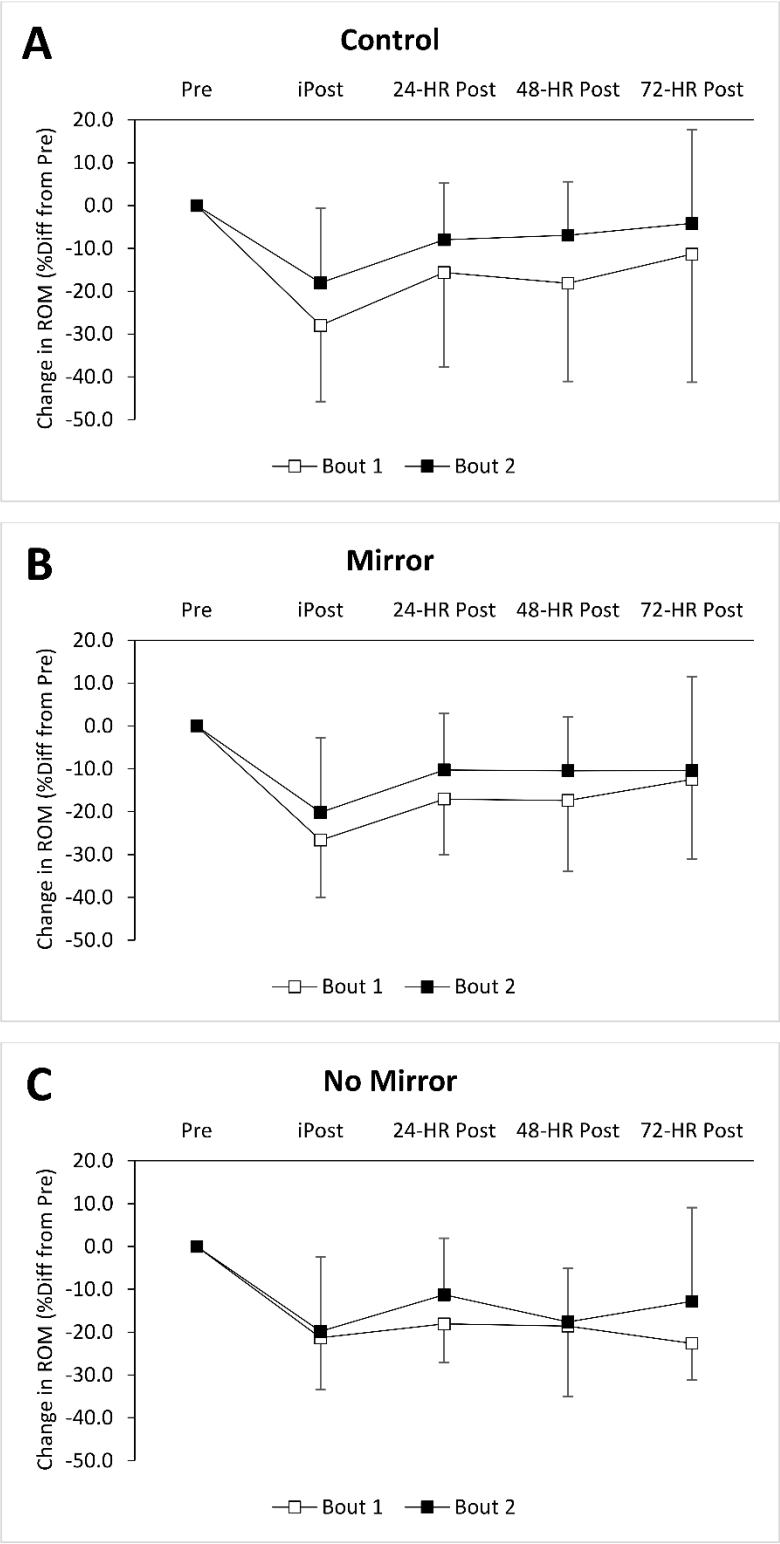



**Figure 6** – Separate analysis comparing the change in ROM over time (Post, 24H, 48H, 72H) between Bout 1 and Bout 2. There was no significant effects detected.

The "protection index" for change in ROM between bouts can be seen in Figure 8. The group x time interaction was not significant (p = 0.43). Nor was there a significant main effect for group (p = 0.89) or time (p = 0.98).

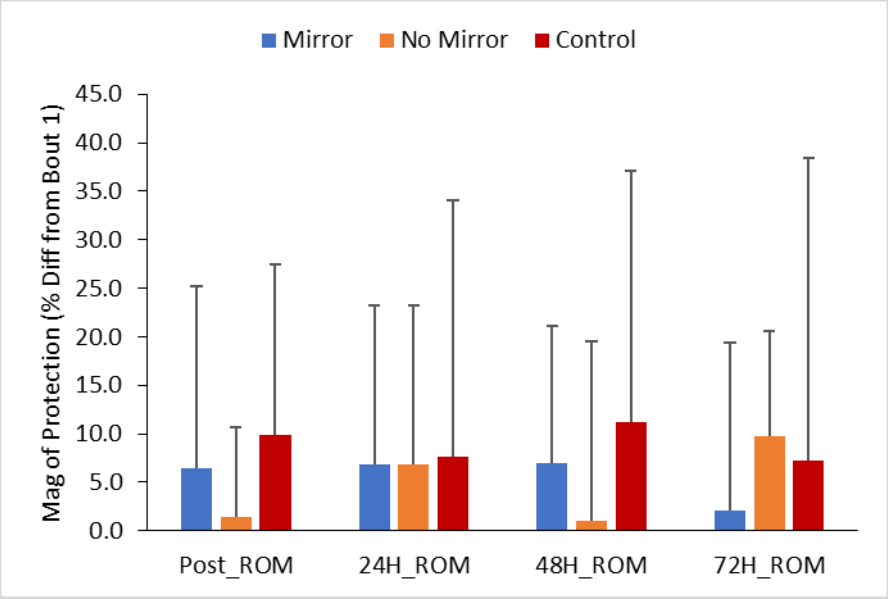



**Figure 7** – Magnitude of protection in range of motion within each group between bouts after repeated bouts of eccentric exercise. No significant differences found.

## 4.04. Muscle Soreness

The results of the three-way (Condition [Mirror, No-Mirror, Control] X bout [Bout 1, Bout 2] x time [Pre, iPost, 24hr, 48hr, 72hr]) repeated measures ANOVA for muscle soreness of the elbow flexors showed a significant three-way interaction (p = 0.014). Muscle soreness over time in each group and in both bouts can be seen in Figure 9. Absolute values for muscle soreness ratings across conditions and between bouts post-exercise can be found in Table 4.

**Table 4** Change in Muscle Soreness Ratings by Condition & Bout (Mean ± SD) Post-Exercise

| Condition | Control | | Mirror | | No Mirror | |
|---|---|---|---|---|---|---|
| | Bout 1 | Bout 2 | Bout 1 | Bout 2 | Bout 1 | Bout 2 |
| DOMS (0-100) | 38.46 ± 22.73 | 13.46 ± 12.41 | 49.73 ± 22.12 | 39.15 ± 26.28 | 57.60 ± 22.71 | 46.96 ± 24.03 |

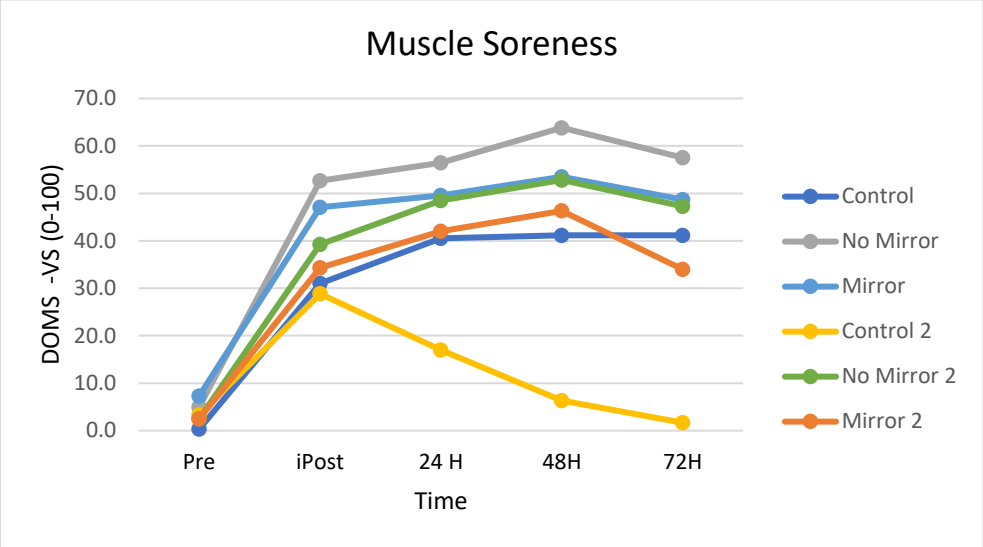



**Figure 8** - Muscle Soreness before and after (Post, 24H, 48H, 72H) repeated bouts of eccentric exercise. Values are means; SD not shown for clarity.

Separate analysis comparing the change in DOMS over time between Bout 1 and Bout 2 in each group was performed using a 2 (Bout) x 4 (Time Point) ANOVA and can be seen in Figure 10. For the control group, the bout x time interaction was significant ($p = 0.02$). Follow-up 1-way ANOVAs for each bout found that values did not differ over time in bout 1 ($p = 0.38$), but did in bout 2 ($p < 0.001$) with values from 24, 48, and 72-HR post exercise differing from each other ($p < 0.04$). When compared between bout 1 and bout 2, ratings of DOMS did not differ at iPost ($p = 0.75$), but did differ at 24-HR ($p = 0.04$), 48-HR ($p = 0.003$), and 72-HR ($p = 0.02$) post exercise (Fig 10A). In the Mirror group, the bout x time interaction was not significant ($p = 0.54$) nor was there a main effect for bout ($p = 0.11$) or time ($p = 0.32$; Fig 10B). In the No Mirror condition, the bout x time interaction was not significant ($p = 0.71$). However, like the control group there was a main effect for bout ($p = 0.009$; Fig 10C) with Bout 2

demonstrating less DOMS (reduced EIMD) than Bout1. There was no main effect for time (p = 0.13).

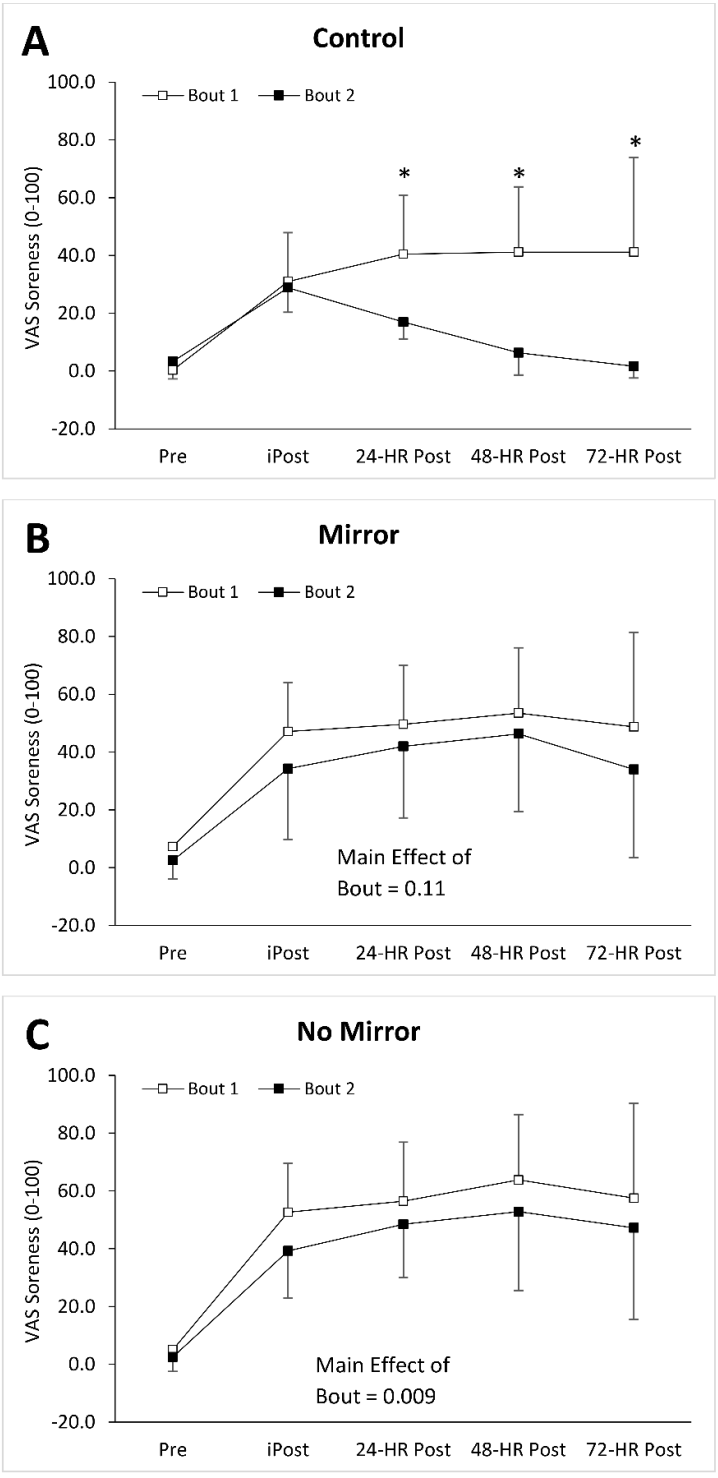


**Figure 9** - Separate group analysis comparing muscle soreness over time (Post, 24H, 48H, 72H) between Bout 1 and Bout 2. In the control group (A) the symbol (*) denotes a significant effect of bout at the specific time point. In the No Mirror group (C) there was a significant effect of bout

The "protection index" for change in DOMS between bouts can be seen in Figure 11. The group x time interaction was significant ($p = 0.02$). Follow-up 1-way ANOVAs indicated no differences among the 3 groups at iPost or 24-HR post eccentric exercise. However, the groups differed at 48-HR and 72-HR post ($p < 0.001$) with the Control group demonstrating greater protection ($p < 0.01$).

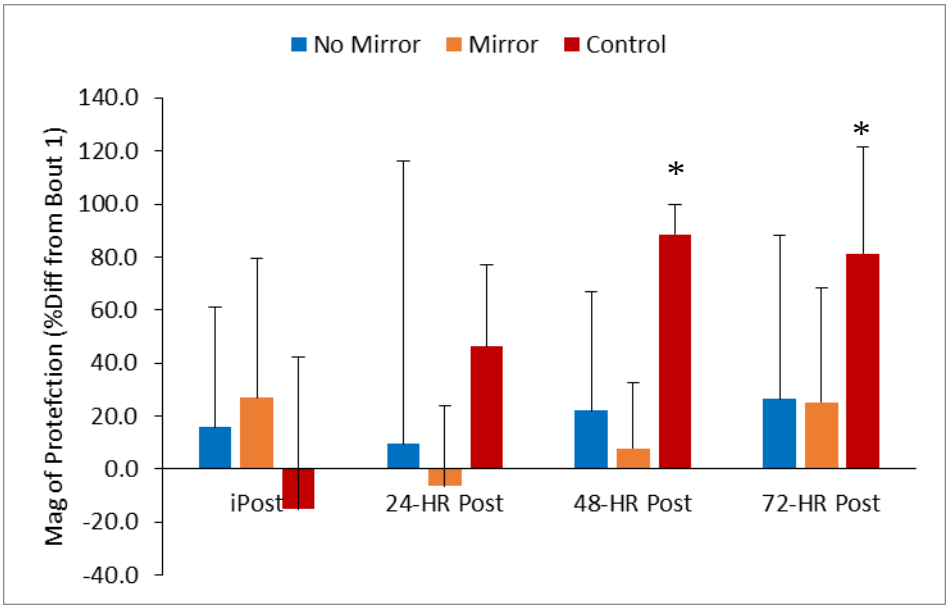



**Figure 10** - Magnitude of protection in muscle soreness within each group between bouts after repeated bouts of eccentric exercise. (*) denotes a significance difference between groups at time points 48-HR and 72-HR post with the control demonstrating the largest protection index at 48HR & 72-HR post (p=0.02)

## 4.05. EMG RMS

### Biceps EMG

The results of the three-way (Condition [Mirror, No-Mirror, Control] X bout [Bout 1, Bout 2] x contraction [1…24]) repeated measures ANOVA for EMG RMS for the biceps during the eccentric exercise bout did not show a significant three-way effect (p=0.425). As such data from each of the 24 eccentric contractions was averaged for each bout. A 2 (bout) x 3 (group) ANOVA was performed to analyze differences in EMS RMS and can be seen in Figure 12. The bout x group interaction was not significant (p = 0.72) nor was there a main effect for bout (p = 0.66) or group (p = 0.24).

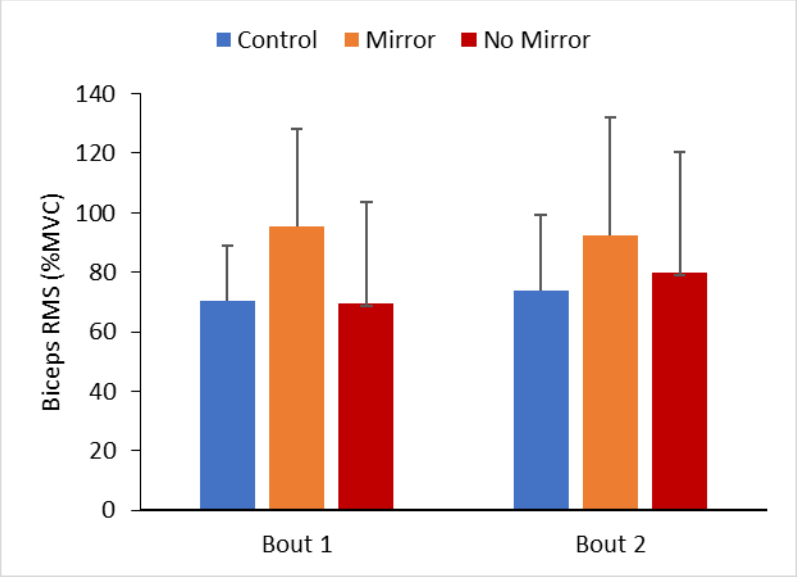



**Figure 11** – Biceps RMS averages by group. Mean RMS values were normalized and expressed as a percentage of the mean RMS values from biceps brachii during biceps MVC. No significant differences found

### Triceps EMG

The results of the three-way (Condition [Mirror, No-Mirror, Control] X bout [Bout 1, Bout 2] x contraction [1…24]) repeated measures ANOVA for EMG RMS for the triceps during the eccentric exercise bout did not show a significant three-way effect (p=0.656). As such data from each of the 24 eccentric contractions was averaged for each bout. A 2 (bout) x 3 (group) ANOVA was performed to analyze differences in EMS RMS and can be seen in Figure 13. The bout x group interaction was not significant (p = 0.22) nor was there a main effect for bout (p = 0.75) or group (p = 0.22).

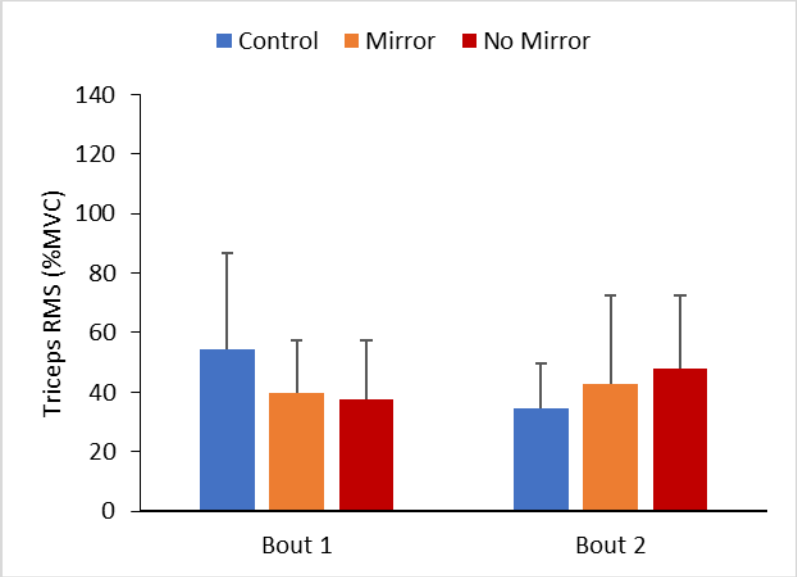



**Figure 12** - Triceps RMS averages by group. Mean RMS values were normalized and expressed as a percentage of the mean RMS values from triceps during triceps MVC. No significant differences found

# CHAPTER 5: DISCUSSION & CONCLUSIONS

## 5.01. Purpose and Hypothesis

The purpose of this study was to examine the contralateral RBE following a unilateral eccentric bout with and without visual mirror feedback. The present study showed mixed results in regards to the indirect markers muscle soreness and isometric maximal voluntary contraction. With a RBE being observed in the control group for MVC and DOMS, as expected. Interestingly, a CL-RBE was observed in the No Mirror group for MVC and DOMS, but not in the Mirror group. This finding in the Control and No Mirror group is consistent with other findings (Howatson & Someren, 2007; Chen et al., 2016; Hyldahl et al., 2017). All groups were less sore after the 2$^{nd}$ bout of eccentric exercise, with the control group and no mirror group reaching statistical significance. Even though there was an improvement in recovery of range of motion over time in bout 2 in all groups, it was shown to not be statistically significant and thus no RBE or CL-RBE was observed. It was hypothesized that the decrease in MVC, ROM, and amount of muscle soreness in the Mirror group would be less than that observed in the No Mirror group. Based on the results, none of the hypotheses investigating the RBE are supported, therefore, the null hypotheses are accepted. This study also looked to examine any possible neuromuscular changes that could underlie the CL-RBE. The results show that there was no differences among groups when looking at biceps and triceps EMG RMS during the 24 eccentric contractions. Therefore, we accept the null hypothesis that MVF will lead to greater EMG amplitude and accept the null hypothesis that MVF will lead to reduced triceps EMG amplitude.

**5.02 – Contralateral RBE**

The Control group and the No Mirror group both exhibited a RBE, with the Control group leading in magnitude, which had MVC and soreness values return very closely to pre-test values 72HR after bout 2. The No Mirror group had a weaker magnitude, showing about a significant recovery, but not reaching to pre-test values. This seems to fall in line with the protective effect observed in other studies (Hyldahl et al., 2017). Although there was a significant effect of bout in muscle soreness in the No Mirror group, it seems to have a weaker magnitude compared with what was observed from other studies. This difference in soreness rating in comparison to other studies could be due to the method performed to record soreness. Participants were asked to perform a bicep curl with a light weight relative to their strength with full range of motion. Because the participants are untrained and unfamiliar with their maximum strength and perceived effort, this could inflate muscle soreness scores. Self-reported soreness ratings already vary greatly between individuals as perception of pain and soreness are different for everyone (Tiidus, 2008). This method was chosen as it was deemed to be most practical to real life, however, including another method such as palpation of the elbow flexors, assessment of a pressure pain threshold, or passive movement of the forearm through its full range-of-motion before the bicep curl method used in this study could yield results more akin to studies done before.

The magnitude of protection in the Mirror group produced confounding results as there was an attenuation of muscle soreness at 72HR, which was very similar to the No Mirror group in rating, although statistically insignificant. Despite this, the Mirror group showed a 0% index of protection when looking at the recovery of isometric bicep MVC during this time point. It is possible that difference in recovery of MVC from the experimental groups could be a result of

per person variability. It has been shown that some individuals can lose up to 75% of their MVC where as others only lose 20% (Sayers & Clarkson, 2001). There is also day to day variability within individuals that could play a large role, and due to the nature of the study using individuals who are untrained, it's possible that some individuals exhibit a larger learning and/or training effect throughout study. It may also be beneficial to include recording more days post-exercise as this study had participants come every day for 3 days, whereas some studies have used 5 days. Recording 2 extra days could result in narrowing this variability at the 5 day mark, eliminating the difference in the index of protection seen in this study. Although very improbable, it's also possible for individuals to not fully recover MVC after an eccentric bout longer than 26 days and even up to 89 days. (Sayers & Clarkson, 2001).

**5.03. Neural adaptations**

This study also looks at possible neural adaptations that may occur and cross-over to the non-dominant limb. Results show no significant changes in bicep or triceps activation between bouts during the eccentric exercise protocol. Previous studies of eccentric exercise have shown neural adaptations such as decreases in autogenic spinal inhibition and reduced H-reflex as well as decreases in antagonist muscle activation (Hight et al., 2017; Lepley et al., 2017). These adaptations were shown to have a cross-over effect from the dominant arm to the non-dominant arm, and this supports findings in general that there is a cross education of neural adaptations from unilateral training (Latella et al., 2012; Manca et al., 2017) and from unilateral eccentric exercise (Hortobagyi et al., 1997; Starbuck & Eston, 2012; Lepley et al., 2014; Kidgell et al., 2015; Hyldahl et al., 2017). One of the main hypotheses of this study would be that the Mirror group would exhibit a greater neural adaptation compared to the No Mirror group. In this case,

we were expecting to see a larger decreased co-activation of the triceps and/or an increase in biceps activation during the 2nd bout in the Mirror group, but this did not occur.

A potential consequence of mirror visual feedback during exercise training is that it has the ability to significantly increase motor skill of the untrained limb. This could be the result of improved activity in the brain associated with motor function and in changes in interhemispheric neural communication. In theory, this would improve motor function of the muscle resulting from the increased excitability from increased neural drive or from decreased Ia afferent inhibition. This increase in synchronicity would cause us to activate more overall muscle fibers during maximal eccentric exercise and or allow for less co-activation of the antagonizing muscle. This would result in more activation across all fibers in the muscle leading to more total force being produced as well as tension spread across the whole muscle and its individual fibers. In theory, this could result in more muscle damage occurring, deterring recovery, however neural adaptations can also cause a shift of motor unit recruitment to lower threshold fibers, which are more fatigue and damage resistant. Perhaps it is possible after cross education, motor unit synchronization can aid in the attenuation of muscle damage, however, as mentioned before, the RBE is multifaceted and it is unclear if the muscle-tendon complex, extracellular matrix restructuring, or inflammatory response models elicit a systemic or cross over effect to the unused limb. There is little to no research on the topic, but it is unlikely that ECM may contribute to the cross education of the RBE as the unused limb does not undergo any cell remodeling after unilateral exercise. This could explain why the CL-RBE has been seen to be approximately between 40-60% of the ipsilateral RBE. In this study, activation of the biceps was statistically the same in both bouts according to the biceps EMG data. This could potentially explain why the Mirror group did not show a recovery in MVC after the 2nd bout as individuals

were not able to use a larger pool of fibers or shift motor unit recruitment, thus experiencing muscle damage.

## 5.04. Limitations

In this study we used a mirror set up in which participant's visual attention was directed towards the mirror with the active hand in peripheral view. Although this approach is very practical when using this intervention, it has been shown to possibly produce a less immersive illusion. The mirror placement itself was also on the axilla instead of bisecting the mid-sagittal line, which may also have an impact on immersion, however, mirror placement on the mid-sagittal line while using the dynamometer proved to be impractical and unusable. Though unlikely, the placement of the mirror on the axilla could also have inadvertently caused activation of the muscles in the unused limb due to possible proprioceptive mechanisms, causing a diminished RBE. Another limitation is our sample size. The study was powered based upon the finding of Chen et al. (2016). We encountered two issues: 1) our data were more variable than those reported by Chen, and 2) we had to remove several participants from the study due to a lack of EIMD. Also, their findings for the index of protection were based off on their data from 5 days post-exercise, where the index calculated here was based off data from 3 days post-exercise, so they are not a like for like match in time. Thus, our final sample (n =10 in the Mirror group and n = 12 in No Mirror group) fell below our desired sample size. This likely limited our ability to detect the relatively small changes that seemed to have occurred in the CL-RBE. The testing of additional participants could help clarify our findings.

## 5.05. Significance and Future Study Recommendations

We know that eccentric exercise provides a strong basis of enhancing neuro-motor performance in athletes, untrained individuals, older adults, and in clinical populations (Aagaard, 2018). We also know that individuals who have experienced injuries, have a history of limb injury, or are clinically unable to use the desired limb have shown to have deficits in muscle activity when attempting to use the limb post injury (Presland et al., 2021). It has also been demonstrated that continual sessions of locomotor training have had a significant improvement in upper and lower extremity motor strength and function (Morrison et al., 2018). In general, it would be recommended that programs for most individuals who are temporarily unable to use one limb to explore methods such as eccentric training and mirror therapy in order to induce the RBE as well as improve motor function in the unused limb. For future studies it is recommended that a larger sample size be used as well as the use of a dynamometer where the biceps can be completely isolated. Recording dependent variables up to 5 days post exercise is recommended and it would be interesting to see the use of MVF with lower body extremities as well as the use of MVF over various times between bouts such as 2 weeks or 4 weeks to compare results from the use without MVF. Finding a better mirror placement to improve immersion as well as ease of performing the actual protocol could improve results in neuromuscular adaptations. As stated in the limitations, previous studies have performed mirror therapy on the midsagittal line, stating the importance of the immersion of the mirror image illusion. However, to the researcher's knowledge, there has been no validity criteria established to determine the efficacy of the mirror placement deviating from the mid sagittal line and should be investigated. Previous research using mirror therapy has also been performed over a period of time (i.e., 8 weeks) using rehabilitative or strength programs. It could be possible that the use of a mirror only in one bout could exhibit minimal

beneficial effects and is an intervention that would be needed to be done over a longer period of time over multiple bouts.

## 5.06 Conclusions

The present study provides evidence of the cross-education of the repeated bout effect with indirect markers of muscle damage. These findings are well in line with previously performed studies. However, the main purpose of this study was to examine if there is any enhancement of cross education of the RBE using mirror visual feedback. The present study shows that there is no evidence of enhancement of the cross education effect when using mirror visual feedback. However, more research should be conducted looking at mirror visual feedback as it could possibly add another way to improve rehabilitative paradigms for individuals who are impaired on the opposite limb.

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# APPENDIX A: IRB APPROVAL LETTER

The UNIVERSITY of OKLAHOMA

**Institutional Review Board for the Protection of Human Subjects**

**Approval of Initial Submission – Expedited Review – AP01**

**Date:** February 15, 2023 **IRB#:** 15529

**Principal Investigator:** Christopher D Black, PhD

**Approval Date:** 02/15/2023
**Status Report Due: 01/31/2024**
**Study Title:** Cross-Education of the Repeated Bout Effect after Unilateral Eccentric Exercise with and without Mirror Visual Feedback
**Expedited Category:** 6 & 7
**Collection/Use of PHI: Yes**

On behalf of the Institutional Review Board (IRB), I have reviewed and granted expedited approval of the above-referenced research study. To view the documents approved for this submission, open this study from the *My Studies* option, go to *Submission History*, go to *Completed Submissions* tab and then click the *Details* icon.

**Requirements under the Common Rule have changed. The above-referenced research meets one or more of the circumstances for which continuing review is not required. However, as Principal Investigator of this research, you will be required to submit an annual status report to the IRB.**

As principal investigator of this research study, you are responsible to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related per IRB policy.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- **Submit an annual status report to the IRB to provide the study/recruitment status and report all harms and deviations that may have occurred.**
- **Submit a final closure report at the completion of the project.**

If you have questions about this notification or using iRIS, contact the IRB @ 405-325-8110 or irb@ou.edu.

Cordially,

Aimee Franklin, Ph.D.
Chair, Institutional Review Board

# APPENDIX B: INFORMED CONSENT FORM

**Signed Consent to Participate in Research**

**Would you like to be involved in research at the University of Oklahoma?**

I am Richard Yang, a member of Dr. Chris Black's Sensory and Muscle Function Lab in the Health and Exercise Department. We invite you to participate in our research project entitled "Cross-Education of the Repeated Bout Effect after Unilateral Eccentric Exercise With and Without Mirror Visual Feedback". This research is being conducted at the University of Oklahoma Norman Campus. You were selected as a possible Participant because you are a healthy male or female between the ages of 18-35 with no known cardiovascular or neurological diseases and you are free from any upper body injuries. Preferably, you must have not resistance trained in the arms in the past 6 months. You must be at least 18 years of age to participate in this study.

**Please read this document and contact me to ask any questions that you may have BEFORE agreeing to take part in my research**

**What is the purpose of this research?** The purpose of this research is to explore the effects of the cross education of the repeated bout effect on the contralateral limb after a bout of eccentric exercise of the elbow flexors with the use of a mirror for visual feedback.

**How many participants will be in this research?** About 46 people will take part in this research. You will be randomly assigned to one of 3 groups. Group 1: Mirror Feedback, Group 2: No Mirror Feedback, Group 3: Same Arm Control (no mirror).

The Mirror and No Mirror Feedback groups will perform intense eccentric exercise with 1 arm and will then perform the second bout of intense eccentric exercise 1 week later with their opposite arm. The Same Arm Control group will perform both bouts of eccentric exercise with the same arm separated by 2 weeks.

**What will I be asked to do?** If you agree to be a in this research, you will be asked to visit the sensory and muscle function lab at the University of Oklahoma Norman Campus on 11 separate occasions.

**Visit 1&2 – Paperwork and Familiarization to Exercise Protocol**

During the first visit you will fill out the required paperwork such as the informed consent, HIPAA, menstrual cycle history, and Physical Activity Readiness Questionnaire (PAR-Q). You will then be familiarized with completing a maximal voluntary contraction (MVC) of the elbow flexors (biceps). This will involve contracting your bicep as hard as you can for 3-5 seconds. The second visit will be a continuation of familiarization of the maximal voluntary contraction. We will then assign you to be in one of the experimental groups (mirror vs. no mirror vs. same arm control). The first visit may take 45-60 minutes and the second will take 15-30 minutes.

**Visit 3 – Eccentric Exercise Visit 1**

During this visit you will first perform a rating of muscle soreness in your biceps and have the range-of-motion of your elbow assessed. You will then perform 3 MVC's with your biceps. You

will then perform the eccentric exercise protocol which will consist of 3 sets of 8 repetitions of maximal eccentric contractions (the lowering phase of a bicep curl to where your arm is fully extended / locked out) of the elbow flexors (Biceps muscle) with or without the use of a mirror depending on group assignment. Electromyography (EMG) of the biceps and triceps will be taken during this time. This will involve placing small (1.5 inch) electrodes on your biceps and triceps muscles to record electrical activity in the muscles during exercise. Two minutes of rest will be provided between each set. After exercise you will again rate your muscle soreness, perform an MVC, and have your elbow range-of-motion re-assessed. This visit will take approximately 30-45 minutes.

There is minimal risk of physical injury during this protocol. If at any time during the eccentric exercise you experience pain that you feel is uncommon for exercise or if the pain is extreme, please cease contractions and inform the researcher.

**Visits 4-6 – Follow-Up**

You will then be required to return to the lab each day for the next 3 days (24, 48, and 72 hours). You will perform an MVC, rate your muscle soreness, and have your range-of-motion assessed during each visit. Each visit for data collection will take approximately10-15 minutes.

**Visit 7 – Eccentric Exercise Visit 2**

This visit will occur 7 days after eccentric exercise visit 1 if you are in the mirror or the no mirror groups. These two groups will perform the protocol on the opposite arm from eccentric exercise visit 1. It will occur 14 days after eccentric exercise visit 1 if you are in the same arm control group.

All measures and exercise will be performed exactly as described for Eccentric Exercise Visit 1 except with the opposite arm if you have been assigned to one of those groups. MVC, soreness, and range-of-motion will be assessed, 3 sets of 8 maximal eccentric contractions will be performed followed by MVC, soreness, and range-of-motion being re-assessed. This visit will take approximately up to 30-45 minutes.

There is minimal risk of physical injury during this protocol. If at any time during the eccentric exercise you experience pain that you feel is uncommon for exercise or if the pain is extreme, please cease contractions and inform the researcher.

**Visits 8-10 – Follow-Up Part 2**

You will then be required to return to the lab each day for the next 3 days (24, 48, and 72 hours) and then 7 days after visit 7 . You will perform an MVC, rate your muscle soreness, and have your range-of-motion assessed during each visit. Each visit for data collection will take approximately10-15 minutes.

**How long will this take?** Your participation will take approximately up to 3½-5 hours over the course of 2-3 weeks depending on your group assignment.

**What are the risks and/or benefits if I participate?** There are no benefits from being in this research. As with any physical activity, there is minimal risk of musculoskeletal injury by participating in this study. In addition, there is minimal risk of developing a condition called exertional rhabdomyolysis. This typically occurs with overexertion during strenuous, novel physical activity, especially in certain populations (liver disease, sickle cell trait). To minimize this risk (<1%), you will be screened for factors that may predispose you to developing rhabdomyolysis and be excluded from participation should you exhibit any factor(s) predisposing you to greater than minimal risk. You will likely experience muscle soreness and discomfort after each eccentric exercise protocol. If at any point you experience severe pain in the exercised arm, greater than expected swelling of your arm, and/or notice your urine is dark red/brown in color contact the researchers immediately. You are encouraged to drink more water than usual while you are in the study and to avoid strenuous exercise with your arms (swimming, lifting weights, carrying heavy objects, boxing, etc.) for the duration of the study.

Participation in this research may include close social contact with the researcher. According to the CDC (www.cdc.gov), the virus that causes COVID-19 is spreading very easily and sustainably between people. Older adults and people who have severe underlying medical conditions like heart of lung disease or diabetes seem to be at higher risk for developing serious complications from COVID-19 illness. Our research protocol includes precautions that follow the CDC guidelines and comply with the current state and/or local restrictions on allowable personal interactions.

**What do I do if I am injured?** If you are injured during your participation, report this to a researcher immediately. Emergency medical treatment is available. However, you or your insurance company will be expected to pay the usual charge from this treatment. The University of Oklahoma Norman Campus has set aside no funds to compensate you in the event of injury.

**Will I be compensated for participating?** You will be compensated with a $20 gift card for your time and participation in this research.

**Who will see my information?** In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely, and only approved researchers and the OU institution Review Board will have access to the records.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not have access to this information until the entire research has completely finished and you consent to this temporary restriction.

**What will happen to my data in the future?** After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you.

**Do I have to participate?** No, if you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any question and can stop participating at any time.


IRB NUMBER: 15529
IRB APPROVAL DATE: 03/(

**Will I be contacted again?** The researcher would like to contact you again to recruit you into this research or to gather additional information.

_____ I give my permission for the researcher to contact me in the future.

_____ I do not wish to be contacted by the research again.

**Who do I contact with questions, concerns, or complaints?** If you have any questions, concerns, or complaints about the research or have experienced a research-related injury, contact me Chris Black, PhD, at 706-255-3750 or cblack@ou.edu

You can also contact the University of Oklahoma – Norman Campus Institution Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participants, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

*You will be given a copy of this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research.*

| Participant Signature | Print Name | Date |
|---|---|---|
| Signature of Researcher Obtaining Consent | Print Name | Date |

# APPENDIX C: HIPAA AUTHORIZATION FORM

**University of Oklahoma Health Sciences CenterResearch Privacy Form 1**
**PHI Research Authorization**

**AUTHORIZATION TO USE or SHARE**
**HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH**
*An Informed Consent Document for Research Participation may also be required.*
*Form 2 must be used for research involving psychotherapy notes.*

Title of Research Project: **Cross-Education of the Repeated Bout Effect after Unilateral Eccentric Exercise With and Without Mirror Visual Feedback.**

Leader of Research Team: **Christopher D. Black, PhD**

Address: **1401 Asp Avenue, #110 SFC, Norman, OK, 73019**

Phone Number**: 303-506-2562 (cell); 405-325-7668 (office)**

If you decide to sign this document, University of Oklahoma Health Sciences Center (OUHSC) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

**PHI To Be Used or Shared**. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, government-issued identification numbers, and nothing else.

**Purposes for Using or Sharing PHI.** If you give permission, the researchers may use your PHI to determine if it is safe for your to participate in the exercise used in this study.

**Other Use and Sharing of PHI**. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OUHSC Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Food and Drug Administration (FDA) and the Department of Health and Human Services (HHS), and when required by law. The researchers may also share your PHI with with your physician and/or a University of Oklahoma physician in the event of a serious health risk or adverse event that occurs during the study.

**Confidentiality**. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

**YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.**

**Voluntary Choice**. The choice to give OUHSC researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OUHSC researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OUHSC.

**Canceling Permission**. If you give the OUHSC researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

**End of Permission.** Unless you cancel it, permission for OUHSC researchers to use or share your PHI for their research will never end.

**Contacting OUHSC**: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

| | | |
|---|---|---|
| Privacy Official<br>University of Oklahoma Health Sciences Center<br>PO Box 26901<br>Oklahoma City, OK 73190 | or | Privacy Board<br>University of Oklahoma Health Sciences Center<br>PO Box 26901<br>Oklahoma City, OK 73190 |

If you have questions, call: (405) 271-2511 or (405) 271-2045.

**Access to Information.** You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

**Giving Permission**. By signing this form, you give OUHSC and OUHSC's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

**Patient/Participant Name (Print):** _____

_____ _____
Signature of Patient-Participant Date
or Parent if Participant is a minor

*Or*

_____ _____
Signature of Legal Representative** Date

**If signed by a Legal Representative of the Patient-Participant, provide a description of the relationship to the Patient-Participant and the authority to act as Legal Representative:

_____
OUHSC may ask you to produce evidence of your relationship.

***A signed copy of this form must be given to the Patient-Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.***




IRB NUMBER: 15529
IRB APPROVAL DATE: 02/15/2023

## APPENDIX D: THE PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

# 2022 PAR-Q+

### The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

## GENERAL HEALTH QUESTIONS

| Please read the 7 questions below carefully and answer each one honestly: check YES or NO. | YES | NO |
|---|---|---|
| 1) Has your doctor ever said that you have a heart condition ☐ **OR** high blood pressure ☐? | ☐ | ☐ |
| 2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity? | ☐ | ☐ |
| 3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise). | ☐ | ☐ |
| 4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** _____ | ☐ | ☐ |
| 5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** _____ | ☐ | ☐ |
| 6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it **does not limit your current ability** to be physically active. **PLEASE LIST CONDITION(S) HERE:** _____ | ☐ | ☐ |
| 7) Has your doctor ever said that you should only do medically supervised physical activity? | ☐ | ☐ |

**If you answered NO to all of the questions above, you are cleared for physical activity.**
**Please sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.**

- Start becoming much more physically active – start slowly and build up gradually.
- Follow Global Physical Activity Guidelines for your age (https://www.who.int/publications/i/item/9789240015128).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and NOT accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

**PARTICIPANT DECLARATION**

If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

**If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.**

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at www.eparmedx.com before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.



 1 / 4
01-11-2021

# 2022 PAR-Q+

## FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

**1. Do you have Arthritis, Osteoporosis, or Back Problems?**

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

| | | |
|---|---|---|
| 1a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 1b. | Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)? | YES ☐ NO ☐ |
| 1c. | Have you had steroid injections or taken steroid tablets regularly for more than 3 months? | YES ☐ NO ☐ |

**2. Do you currently have Cancer of any kind?**

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

| | | |
|---|---|---|
| 2a. | Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck? | YES ☐ NO ☐ |
| 2b. | Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)? | YES ☐ NO ☐ |

**3. Do you have a Heart or Cardiovascular Condition? This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm**

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

| | | |
|---|---|---|
| 3a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 3b. | Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction) | YES ☐ NO ☐ |
| 3c. | Do you have chronic heart failure? | YES ☐ NO ☐ |
| 3d. | Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months? | YES ☐ NO ☐ |

**4. Do you currently have High Blood Pressure?**

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

| | | |
|---|---|---|
| 4a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 4b. | Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure) | YES ☐ NO ☐ |

**5. Do you have any Metabolic Conditions? This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes**

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

| | | |
|---|---|---|
| 5a. | Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies? | YES ☐ NO ☐ |
| 5b. | Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness. | YES ☐ NO ☐ |
| 5c. | Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet? | YES ☐ NO ☐ |
| 5d. | Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)? | YES ☐ NO ☐ |
| 5e. | Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future? | YES ☐ NO ☐ |



 

# 2022 PAR-Q+

**6.** **Do you have any Mental Health Problems or Learning Difficulties?** This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

| | | |
|---|---|---|
| 6a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 6b. | Do you have Down Syndrome **AND** back problems affecting nerves or muscles? | YES ☐ NO ☐ |

**7.** **Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

| | | |
|---|---|---|
| 7a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 7b. | Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy? | YES ☐ NO ☐ |
| 7c. | If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week? | YES ☐ NO ☐ |
| 7d. | Has your doctor ever said you have high blood pressure in the blood vessels of your lungs? | YES ☐ NO ☐ |

**8.** **Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

| | | |
|---|---|---|
| 8a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 8b. | Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting? | YES ☐ NO ☐ |
| 8c. | Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)? | YES ☐ NO ☐ |

**9.** **Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

| | | |
|---|---|---|
| 9a. | Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments) | YES ☐ NO ☐ |
| 9b. | Do you have any impairment in walking or mobility? | YES ☐ NO ☐ |
| 9c. | Have you experienced a stroke or impairment in nerves or muscles in the past 6 months? | YES ☐ NO ☐ |

**10.** **Do you have any other medical condition not listed above or do you have two or more medical conditions?**

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

| | | |
|---|---|---|
| 10a. | Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months? | YES ☐ NO ☐ |
| 10b. | Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)? | YES ☐ NO ☐ |
| 10c. | Do you currently live with two or more medical conditions? | YES ☐ NO ☐ |

**PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE:** _____

**GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.**



 
01-11-2021

# 2022 PAR-Q+

**If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:**

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

**Delay becoming more active if:**

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

## PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

*I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.*

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____


For more information, please contact

**www.eparmedx.com**

**Email: eparmedx@gmail.com**



**Citation for PAR-Q+**

Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.



The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.



**Key References**

1. Jamnik VK, Warburton DER, Makarski J, McKenzie DC, Shephard RJ, Stone J, and Gledhill N. Enhancing the effectiveness of clearance for physical activity participation: background and overall process. APNM 36(S1):S3-S13, 2011.
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3. Chisholm DM, Collis ML, Kulak LL, Davenport W, and Gruber N. Physical activity readiness. British Columbia Medical Journal. 1975;17:375-378.
4. Thomas S, Reading J, and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). Canadian Journal of Sport Science 1992;17:4 338-345.

# APPENDIX E: MENSTRUAL HISTORY QUESTIONNAIRE

**Department of Health and Exercise Science**
**University of Oklahoma**

**MENSTRUAL HISTORY QUESTIONNAIRE**

Participant ID:_____Date:_____

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant (circle your response)

YES- Do not complete the rest of this form
NO- Continue to section A.

**SECTION A: CURRENT MENSTRUAL STATUS**

1. Approximately how many menstrual periods have you had during the past 12 months?
   (please circle what months you have had a period. This means from this time last year to the present month)

**Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec**

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

   _____days. Today is day _____ of your present menstrual cycle.

3. When was the date of the onset of your last period?

4. When do you expect your next period?

5. What is the average length (number of days) of your menstrual flow? _____ days

   How many of these days do you consider "heavy"?_____days

6. Do you take oral contraceptives or any other medication that includes estrogen and/or progesterone?

   If yes, how long have you been taking this medication?_____

   What is the brand name and dosage of this mediation?_____

Has this medication affected your menstrual cycle (regularity, length and amount of flow)? If yes, indicate changes.

IRB NUMBER: 15311
IRB APPROVAL DATE: 01/18/2023

# APPENDIX F: HEALTH SCREENING QUESTIONNAIRE

## FORM 2.2 Health Screening Questionnaire

This questionnaire identifies adults for whom physical activity might be inappropriate or adults who should consult a physician before beginning a regular physical activity program.

### SECTION 1 PERSONAL AND EMERGENCY CONTACT INFORMATION

Name:_____ Date of birth:_____

Address: _____ Phone: _____

Physician's name: _____

Height: _____ Weight: _____

Person to contact in case of emergency

Name: _____ Phone:_____

### SECTION 2 GENERAL MEDICAL HISTORY

Please check the following conditions you have experienced.

***Heart History***

_____Heart attack

_____Heart surgery

_____Cardiac catheterization

_____Coronary angioplasty (PTCA)

_____Cardiac pacemaker/implantable cardiac defibrillator

_____Cardiac rhythm disturbance

_____Heart valve disease

_____Heart failure

_____Heart transplantation

_____Congenital heart disease

***Symptoms***

_____You experience chest discomfort with exertion.

_____You experience unreasonable shortness of breath at any time.

_____You experience dizziness, fainting, or blackouts.

_____You take heart medications.

***Additional Health Issues***

_____You have diabetes (type 1 or type 2).

_____You have asthma or other lung disease (e.g., emphysema).

_____You have burning or cramping sensations in your lower legs with minimal physical activity.

_____You have joint problems (e.g., arthritis) that limit your physical activity.

_____You have concerns about the safety of exercise.

_____You take prescription medications.

_____You are pregnant.

## SECTION 3 RISK-FACTOR ASSESSMENT

***Risk Factors for Coronary Heart Disease***

_____You are a man ≥45 yr.

_____You are a woman ≥55 yr.

_____You smoke or you quit smoking within the previous 6 mo.

_____Your blood pressure is ≥140 or ≥90 mmHg.

_____Your total cholesterol is ≥200 mg · $dl^{-1}$, or low-density lipoprotein (LDL-C) is ≥130 mg · $dl^{-1}$, or high-density lipoprotein (HDL-C) is <40 mg · $dl^{-1}$.

_____You have prediabetes.

_____You have a close male blood relative (father or brother) who had a heart attack or heart surgery before the age of 55 or a close female blood relative (mother or sister) who had a heart attack or heart surgery before the age of 65.

_____You are physically inactive (you do not participate in at least 30 min of moderate intensity (40%-60% $\dot{V}O_2R$) physical activity at least 3 days · $wk^{-1}$).

_____Your body mass index (BMI) is ≥30 kg · $m^{-2}$ or your waist circumference is >40 in. (102 cm) for men or >35 in. (89 cm) for women.

## SECTION 4 MEDICATIONS

Are you currently taking any medication? ❍ Yes ❍ No

If yes, please list all of your prescribed medications and how often you take them, whether daily (D) or as needed (PRN).

_____

_____

Of the medications you have listed, are there any you do not take as prescribed?

## SECTION 5 PHYSICAL ACTIVITY PATTERNS AND OBJECTIVES

List the type, frequency, intensity (e.g., light, moderate, vigorous), and duration of your weekly exercise. Note the intensity at which you plan to exercise and list the specific goals for your exercise program.

Please inform the fitness professional immediately of any changes that occur in your health status.

***Patient Information Release Form***

If you have answered *yes* to questions indicating that you have significant cardiac, pulmonary, metabolic, or orthopedic problems that may be exacerbated with exercise, you agree it is permissible for us to contact your physician regarding your health status in compliance with the Health Information Portability and Accountability Act of 1996 (HIPAA).

Signature: _____ Date: _____

Fitness staff signature: _____ Date:_____

To be completed by fitness professional (circle one):

AHA and ACSM risk stratification: ❍ Low ❍ Moderate ❍ High

Physician consent: ❍ Yes ❍ No



From E.T. Howley and D.L. Thompson, 2012, *Fitness professional's handbook*, 6th ed. (Champaign, IL: Human Kinetics). Adapted from American College of Sports Medicine 2010.

# APPENDIX G: RHABDOMYALSIS SCREENING

**Screening questionnaire**

Participant ID:_____
Date: _____

1. Do you participate in some form of physical activity at least 3 days per week? Yes or No
2. If you answered "Yes" to #1, please list and describe the type and frequency of activity in which you typically engage
   _____
   _____
   _____
3. Have you had any shoulder, elbow, and/or wrist injuries in the previous 6 months? Yes or No
4. Have you taken any type of pain relievers within the previous 7 days? Yes or No
5. Are you taking any medications, prescription or over-the-counter including birth control? Yes or No
6. If you answered "Yes" to #4 or 5, please list the medications, the reasons for taking them, the prescribed dosage, and how long you have been taking them on a consistent basis.
   _____
   _____
   _____
7. Have you consumed any alcohol, tranquilizers, sleeping pills, antidepressants, opiates, cocaine, amphetamines, PCP, or barbiturates within the previous 7 days days? Yes or No
8. Have you consumed any antibiotics, laxatives, diuretics, neuroleptics, or theophyline within the previous 7 days? Yes or No
9. Are you consuming any performance enhancing drugs? Yes or No
10. Are you consuming any vitamins or dietary supplements? Yes or No
11. If you answered "Yes" to #7 to 10, please list what you have been taking?
    _____
    _____
    _____
12. Have you been ill within the previous week or are you currently ill (cold, flu, etc.)? Yes or No
13. Have you made in changes in your diet in the last month? Yes or No
14. Do you have to maintain a specific type of diet for any reason? Yes or No
15. If so, why are you having to maintain the diet?
    _____
    _____
16. Have you been diagnosed with diabetes or high blood pressure? Yes or No
17. Do you have any history of kidney or liver dysfunction? Yes or No
18. Do you have any history of heat illness? Yes or No
19. Do you have any history of swelling after exercise? Yes or No
20. Do you have any history of bruising easily? Yes or No
21. Do you have a family history of muscle disease? Yes or No
22. Are you currently undergoing statin or thyroid replacement therapy? Yes or No

## APPENDIX H: RECRUITMENT FLYER

# Interested in Muscle Damage and Cross Education from one limb to another?

# Research Participants Needed

The Sensory and Muscle Function Lab is conducting a study titled:
*Cross-Education of the Repeated Bout Effect after Unilateral Eccentric Exercise with and without Mirror Visual Feedback*

**To Participate**

- Be a female between 18-35 years of age
- Healthy participants with no cardiovascular or neurological disorders, free from any arm musculoskeletal injuries
- Not taking any medications (OTC or Prescription) that have an effect on muscle function
- Females: you are not pregnant and have a regular menstrual cycle
- Participants must not have performed regular arm resistance training in the past 6 months

**10 Visits Required**

- Total time commitment is approximately 4 hours
- First visit will take ~30-45 minutes and second visit ~15-30 minutes
- The two experimental visits will take ~1 hour
- The 6 follow-up visits will take ~10 minutes
- Testing will take place in the Sensory and Neuromuscular Function Lab at the University of Oklahoma Norman Campus

**Compensation**

- You will be compensated for your time in the form of a gift card

If you are eligible and interested, please contact:

Richard Yang, ryang@ou.edu, or Dr. Chris Black (Primary Investigator), cblack@ou.edu

The University of Oklahoma is an equal opportunity institution.

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